WAR DEPARTMENT

CORPS OF ENGINEERS

MISSISSIPPI RIVER COMMISSION

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER
MISSISSIPPI

TECHNICAL MEMORANDUM NO. 2-223

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

MRC-WES-150-FEB 47

MARCH 1947

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAR 1947**	2. REPORT TYPE	3. DATES COVERED **00-00-1947 to 00-00-1947**
4. TITLE AND SUBTITLE **Model Study of Spillway Enid Dam, Yocona River Mississippi**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Corps of Engineers,Waterway Experiment Station,3903 Halls Ferry Road,Vicksburg,MS,39180**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**111**	


SPILLWAY–
ENID DAM
ORIGINAL DESIGN

CONTENTS

MODEL STUDY OF THE SPILLWAY

FOR

ENID DAM, YOCONA RIVER, MISSISSIPPI

SYNOPSIS

The model study of the spillway for Enid Dam, proposed for construction on the Yocona River in Mississippi, was concerned with hydraulic performance of the spillway, particularly as affected by the use of sloping sidewalls for the spillway chute and stilling basin. This study was of an unusual nature in that it was concerned chiefly with hydraulic-jump action within a stilling basin of trapezoidal cross section, a subject on which very little information is available. It was determined from the model study that certain alterations of the original spillway design were necessary to improve hydraulic performance.

In the original design, the projection formed just below the spillway crest by intersection of the side walls of the chute and the approach channel caused standing waves on the chute. Alleviation of this condition was accomplished by extending the chute walls farther upstream to intersect the approach channel walls either at, or upstream from, the spillway crest.

The performance of the stilling basin as originally designed was found to be unsatisfactory, and 36 alternate designs were investigated. It was demonstrated that satisfactory stilling action could be obtained in a trapezoidal stilling basin (with sloping side walls) by either of two methods: (a) arching the floor of the spillway chute, or (b)

constructing large deflector blocks on the chute near its junction with the basin. (In either of these cases, an end sill and two rows of baffle piers were required.) This fact notwithstanding, the model tests clearly indicated the superiority of the standard rectangular stilling basin (vertical side walls) for providing good flow conditions in the basin proper. Furthermore, velocities over the riprapped side slopes of the exit channel were lower with the rectangular basin than with the trapezoidal basin. It was also demonstrated by the model tests that sloping or vertical side walls for the spillway chute would operate with equal efficiency, provided that proper transitions were effected between the walls of the chute and the stilling basin.

Although the model study indicated the superiority of a rectangular section for the stilling basin, consideration should be given to the practicability of using a trapezoidal basin in cases where this design is clearly indicated by considerations of economy of construction or availability of materials.

PART I: INTRODUCTION

1. A hydraulic model study of the spillway for Enid Dam was recommended by the President, Mississippi River Commission, in a letter dated 6 February 1943 to the Chief of Engineers, U. S. Army. Authority for the study was granted by the Chief of Engineers in letter of 9 February 1943 to the President, Mississippi River Commission. The model study was conducted by the U. S. Waterways Experiment Station during the period February to December 1943.

2. The original design of the proposed Enid Dam spillway was furnished the Experiment Station by the Office of the President, Mississippi River Commission. The model testing program included various features of design and design modifications originating in the Office, Chief of Engineers; the Office of the President, Mississippi River Commission; the Harza Engineering Company (which prepared the original design under contract); and the Experiment Station. Close liaison was maintained between the Experiment Station and the Office of the President, Mississippi River Commission, throughout the course of the model study through consultations with Messrs. George B. Davis and James E. Sanders, Engineers, of the latter office. Progress reports were submitted periodically by the Experiment Station, and test results were forwarded in preliminary reports as data became available.

3. The model study was conducted in the Hydraulics Division under the supervision of Mr. Frederick R. Brown, Engineer, Chief of the Structures Branch. Mr. Brown was assisted by Mr. William B. Tanner, Engineer, and by Mr. Edwin S. Melsheimer, Engineering Aide.

PART II: THE PROTOTYPE*

Design Features of Enid Dam Project

4. Enid Dam is proposed for construction on the Yocona River, at a location approximately 3 miles north of Enid, Mississippi. Figure 1 is a vicinity map of the area. The dam will provide flood protection for the delta reaches of the Yazoo River basin above the head of the Mississippi River backwater. The proposed structure will consist of an earth-fill embankment containing approximately 6,260,000 cu yd of material. The main section of the dam will be about 8,400 ft long, and will have an average height above the valley floor of 78 ft and a maximum height above the bed of the river of 99 ft. The reservoir at spillway-crest elevation will have an area of 28,000 acres, a storage capacity of 660,000 acre-ft,

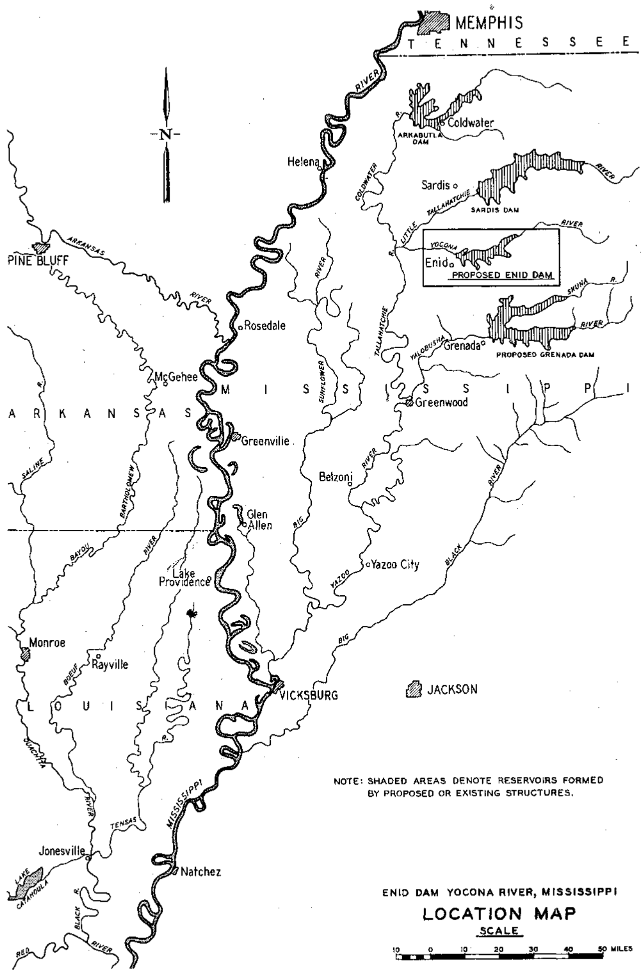


Figure 1

* Information on the prototype was obtained from the "Analysis of Design, Enid Reservoir, Yocona River, Mississippi."

and will extend up the Yocona River valley approximately 20 miles. At conservation or permanent pool elevation of 230*, the reservoir will have an area of 6,100 acres and a storage capacity of 57,600 acre-ft.

5. Reference is made to figure 2 and plate 1 showing details of the spillway and stilling basin as originally designed. It was proposed that this structure, with a 237-ft clear crest width at elevation 268, be located in the north abutment ridge to provide passage for extraordinary floods from a full reservoir. The proposed structure includes a flared approach channel, a low round-crested weir, a 1-on-3 sloped trapezoidal-shaped chute, a trapezoidal-shaped stilling basin, a short outlet channel with derrick-stone and riprap pavement, and an unlined earth pilot channel. The structure is designed to discharge 49,700 cfs with the pool at elevation 284.

6. The following data apply to structural and hydraulic features of the spillway and stilling basin as originally designed:

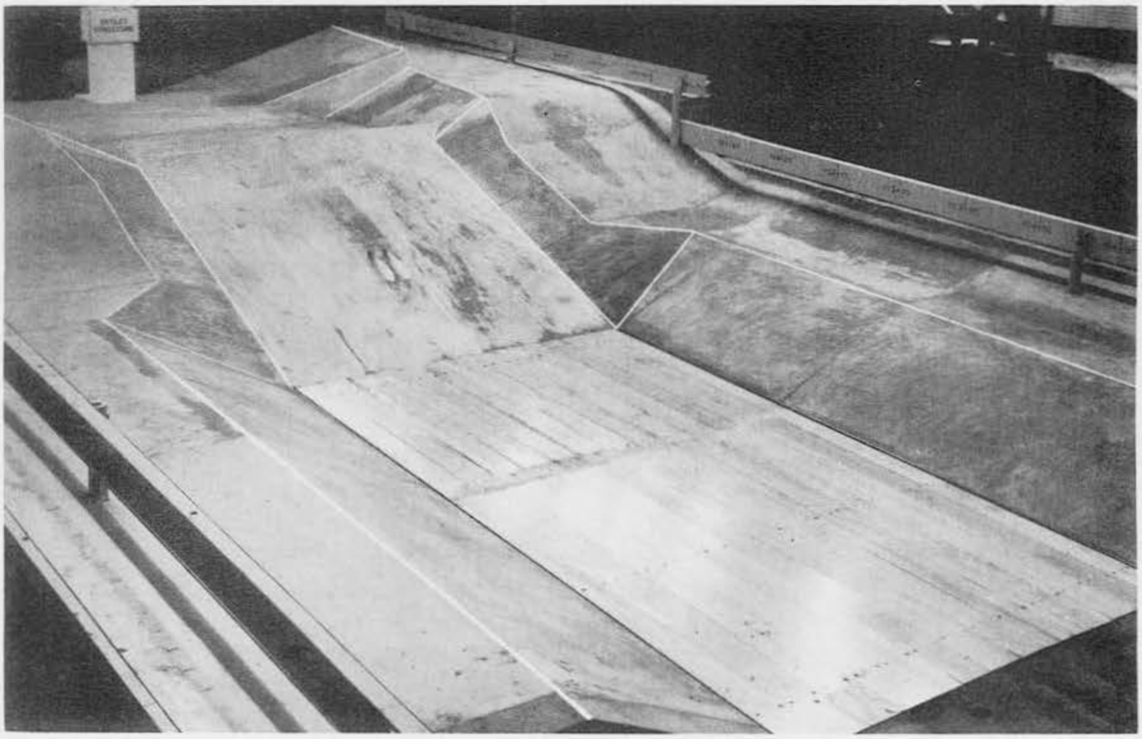
Structural		Hydraulic	
Height of spillway weir	10 ft	Design discharge . .	49,700 cfs
Elevation of crest . . .	268	Design head on crest	16 ft
Width of spillway crest	237 ft	Design headwater elevation	284
Width of chute	200 ft	Minimum tailwater elevation for design discharge .	220.4
Slope of chute	1 on 3	Maximum tailwater elevation for design discharge .	243.6
Length of stilling basin	360 ft		
Width of stilling basin	200 ft		
Elev. of stilling basin	190		

* All elevations are in feet above mean sea level.

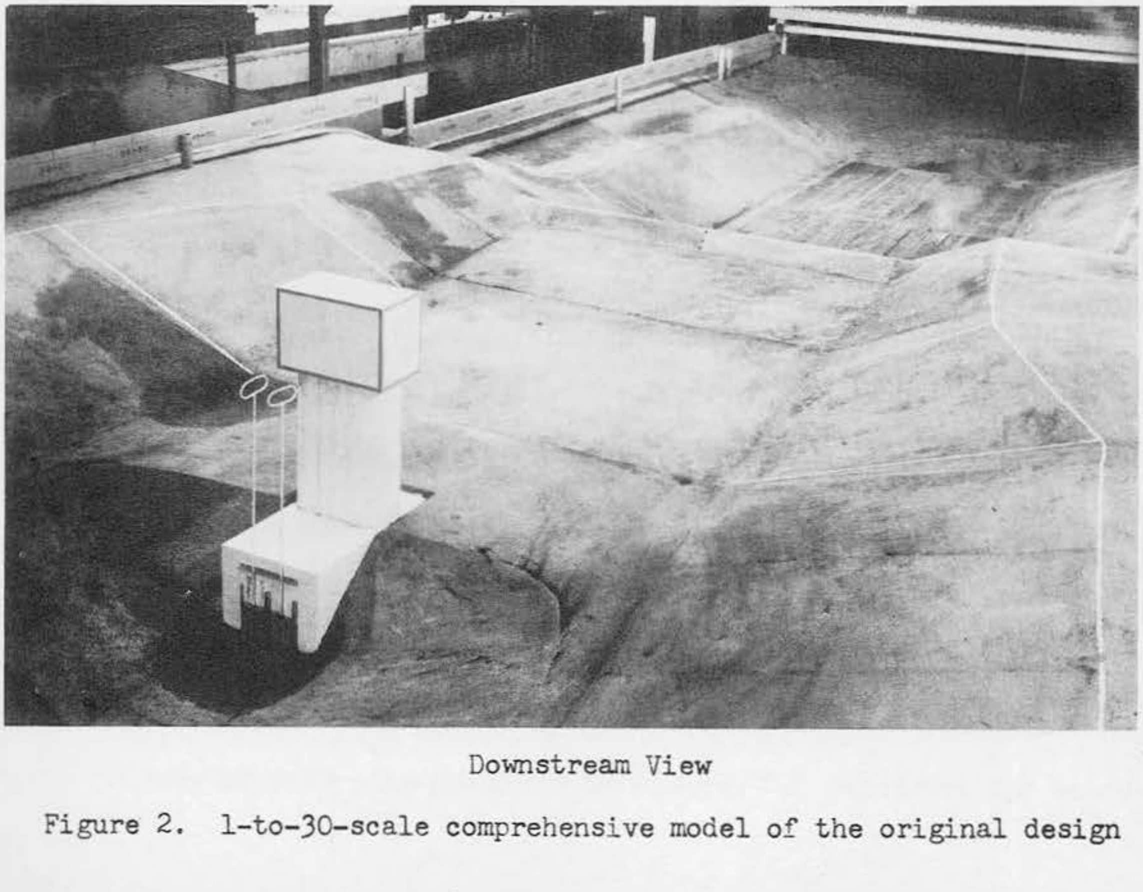
7. The outlet structures as originally designed are shown by figure 2. They were designed to serve the dual purpose of controlling outflow during the flood season, and of emptying the flood-control pool prior to the beginning of the next normal flood season. The type of outlet selected for this purpose was a double, modified, inverted, egg-shaped conduit controlled by a two-gate intake. The inverts of the gates were at elevation 215 and the gate passages were raised at the entrance to form a weir at elevation 227.5. Although this type outlet was utilized in the model study of Enid Dam, later plans indicated that for structural reasons the prototype will probably be constructed with separate outlet structures.

Purpose of the Model Study

8. The general purpose of the model study was to investigate the hydraulic performance of the spillway and appurtenant structures as originally designed, with a view toward developing such design modifications as might be necessary to assure the desired capacity and hydraulic safety of the structures. The model study was particularly concerned with the unusual problem of obtaining hydraulic-jump action in a stilling basin of trapezoidal cross section, as contemplated in the original design. The use of sloping side walls for the chute and stilling basin had been planned as a war-time measure to minimize the amount of steel required for construction.



Upstream View



Downstream View

Figure 2. 1-to-30-scale comprehensive model of the original design

PART III: THE MODEL

Design Considerations

9. Application of the laws of similitude to small-scale models of hydraulic structures has been fully discussed in previous technical memoranda of the Experiment Station. Most important, however, to the design and operation of the Enid spillway model was the consideration that in overfall structures such as this, fluid motion is predominantly affected by the force of gravity; thus, hydraulic quantities vary between model and prototype systems according to the Froudian relationship.

10. In meeting the requirements for complete dynamic similarity between model and prototype systems, the model representation of prototype surfaces must be smoother as the scale ratio decreases. For the scale ratio of 1 to 30 adopted for the Enid model, the roughness scale should be 1 to 1.762. Assuming the roughness of the prototype to be about 0.013, the model roughness should be about 0.0074. In construction of the Enid model, care was taken to make all spillway surfaces as smooth as possible, and a value of about 0.0085 is believed to have been attained. The difference between this value and the theoretically correct value of 0.0074 has been found to be insignificant in the performance of the stilling basin. In the calibration of the spillway, however, the variation in roughness might have resulted in a slight reduction of model spillway efficiency.

11. Relationships for the transference of model data to prototype equivalents, or vice versa, are expressed by the following tabulation, where the subscript r represents the model-to-prototype ratio:

Dimension	Relationship
Length	$L_r = 1/30$
Area	$A_r = L_r^2 = 1/900$
Time	$T_r = L_r^{1/2} = 1/5.477$
Velocity	$V_r = L_r^{1/2} = 1/5.477$
Discharge	$Q_r = L_r^{5/2} = 1/4929$

Interpretation of Model Results

12. Because of the nature of the quantities involved, certain of the model data may be accepted quantitatively, while other data are reliable only in a qualitative sense. Measurements in the model of discharges, water-surface elevations, velocities, and pressures (all positive and negative pressures corresponding to pressures above the cavitation range in the prototype) can be transferred quantitatively from model to prototype by means of the above scale relationships. Evidences of scour, however, are to be considered as only qualitatively reliable, since it has not yet been proven possible to simulate quantitatively in a model the resistance to erosion of a prototype bed material.

Description of the Model

13. The model of Enid Dam spillway was built to the linear-scale ratio of 1 to 30. There were reproduced in the model 420 ft of the approach channel, the spillway crest and chute, the stilling basin, the outlet structures, and about 300 ft of the exit channel. The dimensions of model structures were in accordance with prototype plans and

specifications furnished by the Harza Engineering Company and the Office of the President, Mississippi River Commission.

14. That portion of the model representing the approach channel, the spillway, and overbank areas was molded in cement mortar to sheet-metal templets. The portion of the model representing the exit channel was molded in sand; for velocity tests this sand bed was rendered immovable by application of a thin coating of cement mortar. The intake structure, stilling basin, end sill, and baffle piers were modeled of wood and treated with waterproofing material to prevent expansion. The outlet conduits were shaped in sheet metal. Care was exercised to properly shape all surfaces and to make them as smooth as possible.

15. Water used for operation of the model was supplied by centrifugal and axial-flow pumps connected in such manner as to permit flexibility of pump operation. The water was pumped from a large sump and measured by means of two venturi tubes. The flow from the supply lines spilled into a headbay where it was stilled by baffles prior to its entrance into the model. After passing through the model, the water flowed through an exit channel back to the sump. The tailwater elevation in the lower end of the model was regulated by means of an adjustable tailgate. Steel rails, set to grade along either side of the model, provided a reference plane for the use of measuring devices. Water-surface elevations were measured both by means of portable point gages (mounted on an aluminum beam supported by the steel rails) and by means of piezometers. Piezometers were also used to measure pressures on the spillway crest and chute. Velocities were measured by means of pitot tubes. Soundings over the sand bed below the stilling basin were taken with a portable rod.

Method of Operation

16. To accomplish the purpose of the model study, it was necessary to conduct tests which involved consideration of (a) relation of pool elevation to discharge, (b) water-surface profiles over the spillway and through the stilling basin and exit channel, (c) magnitude of pressures on the spillway crest and chute, (d) depth and location of scour below the stilling basin, (e) magnitude and distribution of velocities in the stilling basin and exit channel, and (f) energy-dissipating characteristics of the stilling basin as observed in the model. Methods used in calibrating the spillway, conducting scour tests, and maintaining tailwater depths are described in the paragraphs which follow.

Spillway calibration

17. The relation of pool elevation in the reservoir to discharge over the spillway was determined in increments from low flows to the maximum flow. Pool elevation for the spillway calibration was determined for each discharge by means of a hook gage used in conjunction with a piezometer gage located in the approach channel.

Scour downstream from stilling basin

18. Prior to conducting scour tests, the bed of the exit channel downstream from the stilling basin was molded flat in sand to elevation 190 and the sides of the exit channel were molded to a 1-on-2 slope. To obtain the required flow conditions, the sand bed was first flooded to prevent unnatural erosion before stable flow conditions were reached. The desired discharge, measured through the venturi meter, was then

introduced into the model. As flow over the spillway became stabilized, the tailgate was adjusted to obtain the required tailwater elevation. Each scour test lasted one hour, during which time the sand bed became relatively stable, and all data pertaining to basin action were recorded. At the conclusion of each test, the exit area was drained and the sand bed was cross-sectioned.

Tailwater

19. Desired tailwater elevations were maintained by means of an adjustable tailgate, and were determined from the approximate maximum and minimum tailwater curves shown on plate 8, furnished by the Office of the President, Mississippi River Commission. The preparation of a maximum and minimum tailwater curve was necessary due to the fact that the design called for excavation of a pilot channel below the spillway, and contemplated the enlargement of this channel by erosion. Maximum tailwater elevations were used in only a few tests, such as those made to determine submergence of the hydraulic jump. The importance of effective stilling action at the shallower depths indicated the advisability of conducting the detailed tests with minimum tailwater elevations.

Flow characteristics

20. In order to establish the general hydraulic performance of the stilling basin and its effect on flow conditions in the exit area, observation tests were made of the energy-dissipating characteristics of each of the stilling-basin designs investigated. These observations were supported by photographs.

PART IV: NARRATIVE OF TESTS

21. Initial model tests were conducted upon the spillway as originally designed. Details of the original design are as shown by figure 2 and plate 1. When all aspects of the original design had been investigated, tests were conducted of various alterations to spillway elements as follows:

   a. Preliminary observation tests of many alterations were first conducted to select designs worthy of further investigation.

   b. Detailed tests were conducted upon those alterations which effected some improvement on the original design as revealed during preliminary observation tests. The detailed tests involved measurement of water-surface profiles, scour, and velocities in the stilling basin and exit channel.

22. The major portion of the testing program concerned experiments on alternate designs for the approach walls and the stilling basin. In presenting the results of the tests, test data are not given according to the chronological order in which the tests were conducted. Instead, each element of the spillway is considered in turn, and all tests conducted thereon are described in detail.

Tests of Approach Channel

Description -- original design

23. The approach channel as originally designed (see figure 2 and plate 2) was flared in plan and had a moderate adverse slope approaching the weir section. The bed of the channel and the side walls were paved for a distance of 246 ft upstream from the spillway crest. In the paved

portion of the channel, a bottom width of 200 ft was maintained. The slope of the side walls varied from 1 on 3 in the flared portion of the approach channel to 1 on 2 at a distance of 130.5 ft upstream from the spillway crest. The 1-on-2 sloping side walls of the approach channel extended 9.9 ft downstream from the crest, where they intersected the 1-on-2.68 sloping walls of the spillway chute.

<u>Results -- original design</u>

24. Flow conditions on the spillway chute were unsatisfactory because of the sharp intersection of the approach and chute walls. The intersection immediately downstream from the crest caused standing waves on either side of the chute which extended into the stilling basin. These standing waves are shown in figure 3 for two conditions of discharge. The flow converged toward the center of the basin at both high and low discharges. Bottom velocities measured throughout the approach area are shown on plate 3. The highest velocity recorded was 9 ft per sec, measured 45 ft upstream from the spillway crest.

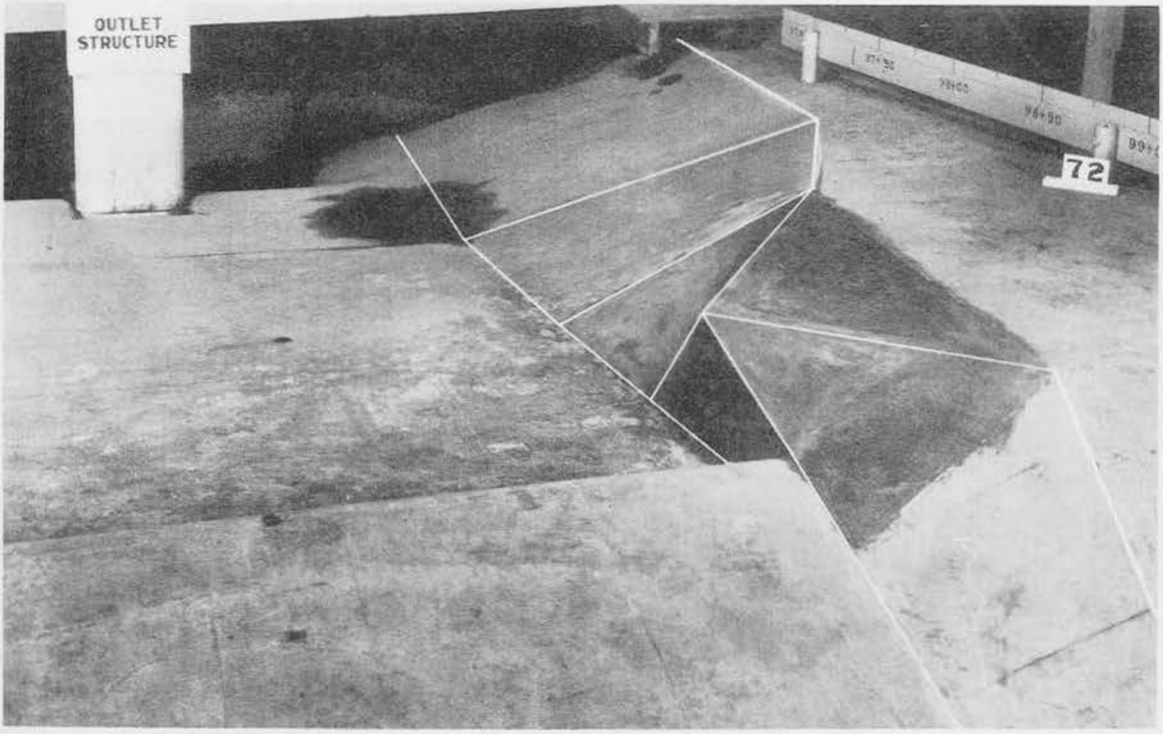
<u>Description -- alternate approach-channel walls (types A and B)</u>

25. Approach-channel wall designs, designated as types A and B, involved alterations to eliminate the waves on the chute caused by the intersection of approach-channel and chute walls. These alternate types of approach-channel walls were formed by extending the chute walls of the original design upstream until they intersected the approach-channel walls at, or upstream from, the spillway crest. The difference between types A and B designs (see figure 4 and plate 2) was the manner in which the transition from approach-channel to chute walls was accomplished.

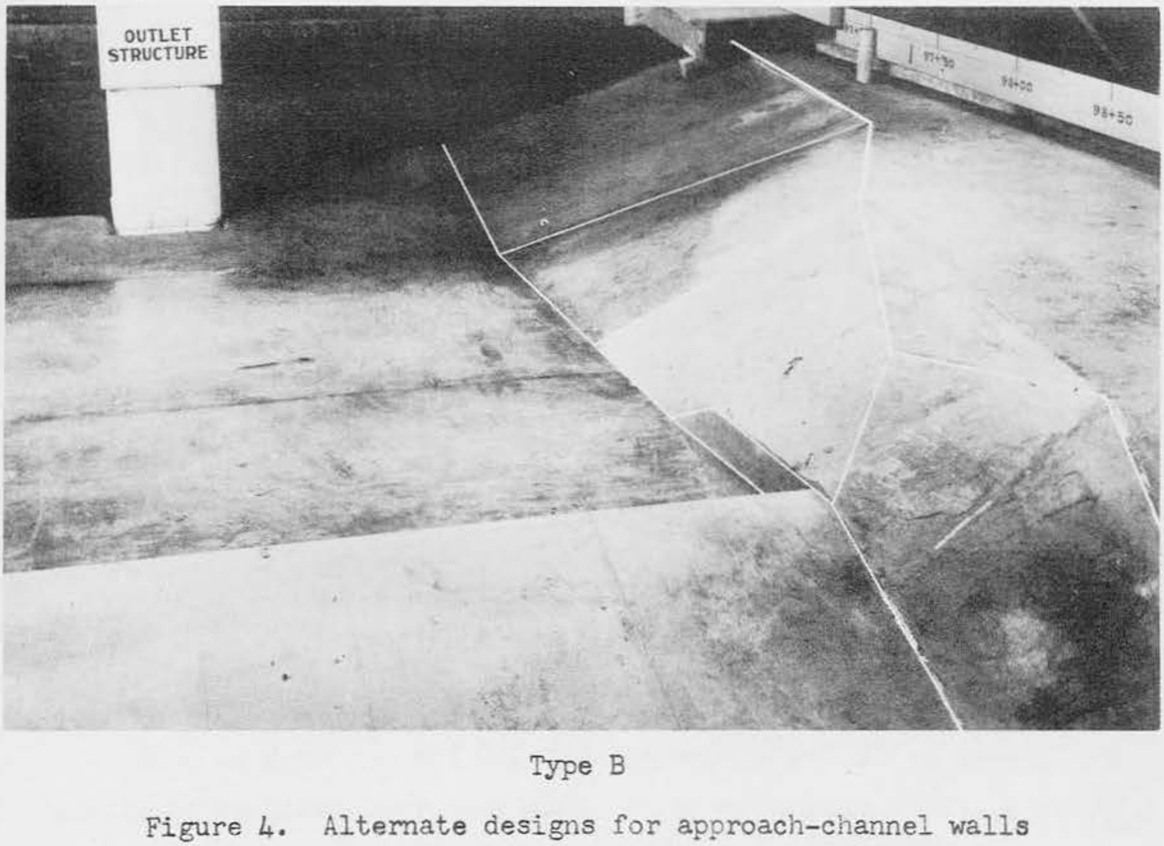
Discharge 50,000 cfs

Discharge 25,000 cfs

Figure 3. Flow conditions with approach-channel walls as originally designed

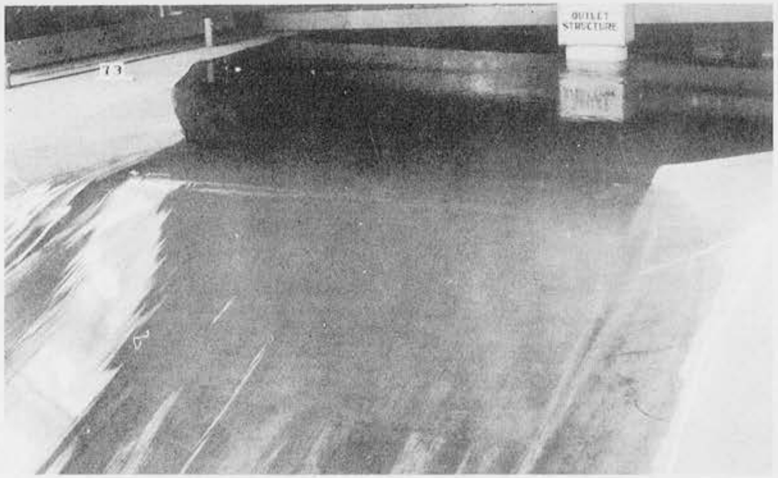


Type A

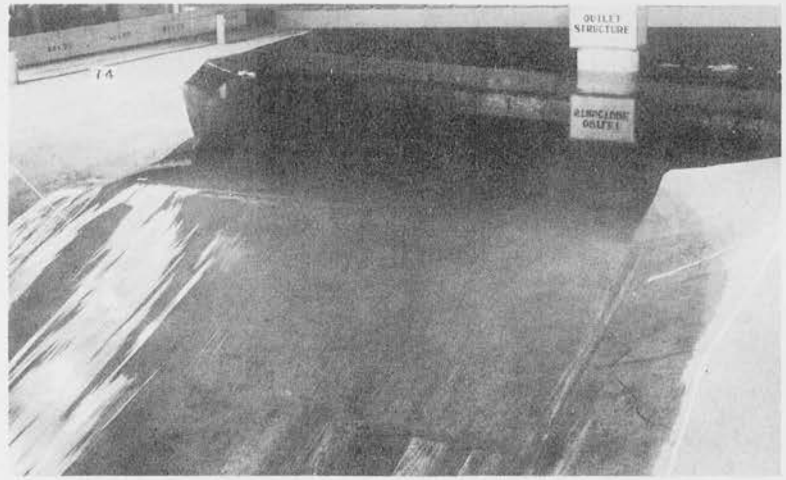


Type B

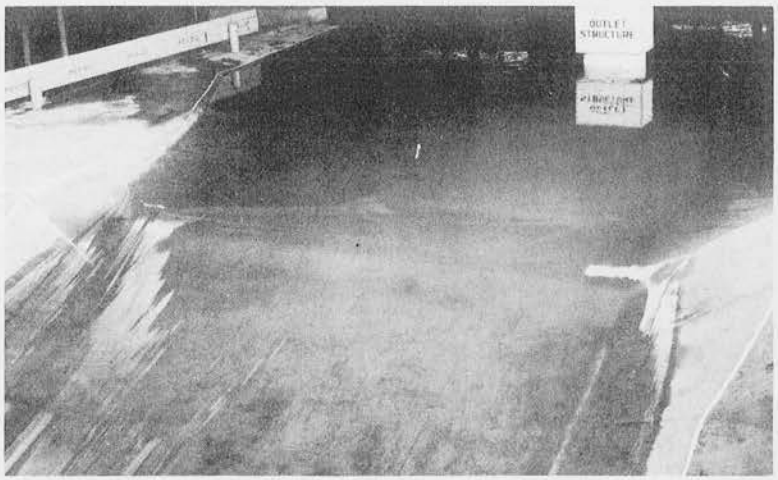
Figure 4. Alternate designs for approach-channel walls



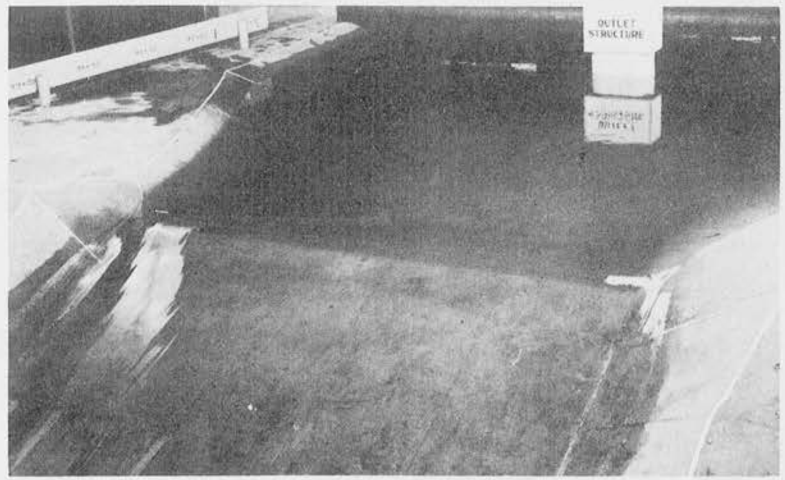
Type A walls. Discharge 50,000 cfs



Type A walls. Discharge 25,000 cfs



Type B walls. Discharge 50,000 cfs



Type B walls. Discharge 25,000 cfs

Figure 5. Flow conditions with alternate designs for approach-channel walls

Immediately upstream from the weir section a portion of the approach-channel wall in each design was made vertical in order to maintain the 200-ft width of spillway and the slope of the side walls.

Results -- alternate approach-channel walls (types A and B)

26. Figure 5 indicates that the types A and B wall revisions accomplished the desired results at both high and low discharges, in that the waves on the spillway chute were eliminated and the flow was smooth and uniform over the crest and chute. Both types of walls are about equally efficient; the choice as to which type is preferable may be based upon their relative costs. Bottom velocities measured in the approach channel with the types A and B walls installed are shown on plate 3. Attention is invited to the fact that bottom velocities recorded with these designs were as high as 12 ft per sec, whereas velocities with the original design did not exceed 9 ft per sec. Revision of the walls also decreased the effective spillway width, but, as discussed in paragraph 29, the discharge at maximum pool level still exceeded the computed design discharge.

Tests of Spillway Weir

Description -- original design*

27. The details of the spillway crest as originally designed are shown on plate 4. It is to be noted that the upstream face of the weir crest has a slope of 1 on 1 from its intersection with the adverse slope

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* Information obtained from "Analysis of Design, Enid Reservoir, Yocona River, Mississippi."

of the approach channel at station 99 + 87.93 (elevation 258) to a point of tangency with a circular curve having a radius of 5 ft, which in turn is tangent at the crest (elevation 268) to a parabolic curve with equation $X^2 = 34.75Y$, where X and Y are coordinates referred to the crest as an origin. This parabolic curve is based on the equation $X^2 = 2.17\ HY$, where H is the design head (16 ft) necessary to discharge 49,700 cfs. The parabolic curve of the crest extends downstream to the point where it becomes tangent to the 1-on-3 slope of the chute at elevation 267.04. In the determination of discharge capacity, the coefficients used were assumed equal to those of a weir having the Creager profile with an upstream slope of 1 on 1. The model investigation of the spillway weir comprised (a) determination of the pool-elevation vs discharge relation, and (b) measurement of water-surface profiles and pressures. Although no alterations were made in the shape of the weir cross section during the course of the model study, several tests were conducted wherein the transverse axis of the weir was curved horizontally. These latter tests are discussed in paragraphs 54 and 55.

Results -- original design

28. Spillway calibration. Reference is made to plate 5, which shows the head-discharge relation for the original spillway design and the effect of the types A and B approach-wall modifications on this relation. These data indicate that the head-discharge relation as computed is not in close agreement with the relation determined from the model. At a pool elevation of 283.4 the model indicated that a discharge of 63,000 cfs could be passed, whereas computations indicated a discharge of only 49,700 cfs at a pool elevation of 284. The discrepancy

between model and computed results is attributed to the fact that the computed results were based on a 200-ft rectangular weir instead of the existing 237-ft trapezoidal weir.

29. Head-discharge relationships with the alternate approach-channel walls are in close agreement with each other, although the rating curves for the alternate approaches show lesser discharges at equivalent heads than the rating curve for the original approach-channel wall design. This again is the result of a change in the cross-sectional area at the crest by variation in wall alignment and slopes. Although the cross-sectional area was reduced, the discharge at maximum pool level was still in excess of the computed discharge, being in the range of 57,000 cfs.

30. Water-surface and pressure profiles. Only one water-surface profile was measured over the spillway at a discharge of 63,000 cfs, since observation of flow conditions with the original approach-channel wall design in place had immediately indicated the necessity for revision. This profile, shown on plate 6, indicates that the height of the spillway walls was sufficient to confine high discharges. Pressures were measured over the spillway crest and chute at the locations shown on plate 7 for discharges of 63,000, 40,000, and 20,000 cfs. The magnitude of pressures recorded is listed in table 1. It will be noted that negative pressures of -1.5 ft and -0.5 ft of water existed at piezometer 10 for discharges of 20,000 and 40,000 cfs, respectively. All other pressures were positive. The decrease in negative pressures at piezometer 10 as the discharge was increased is attributed to the effect of the conduit openings on the chute face.

Tests of Conduits

31. No detailed tests of the conduits were conducted inasmuch as it was decided by the designing engineers during the model study to use separate outlet structures. Observation tests indicated that the energy of flow from the conduits would be satisfactorily dissipated by almost any of the basin designs described in later paragraphs. Figure 6 shows a flow of 3500 cfs being discharged from the twin conduits. The effect of the conduit outlet portals on spillway flow is shown in figure 3, where it may be seen that at low flows the exit portals caused some disturbance of flow conditions. As the discharge increased, however, this disturbance became less apparent.

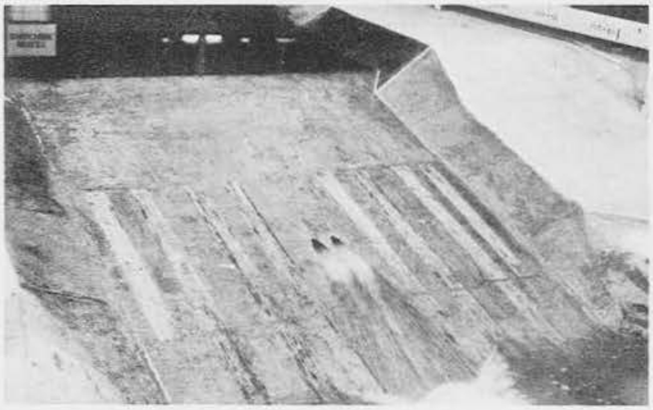


Figure 6. Flow through conduits

Tests of Stilling Basin

32. The proposed stilling basin was of the hydraulic-jump type with the apron placed 2.0 ft above the depth theoretically required for good jump action at the maximum computed discharge of about 50,000 cfs. Inasmuch as little data were available concerning the effect of a trapezoidal-shaped channel on jump-action, the investigation of stilling basin performance became the most important phase of the model study. The use of a trapezoidal-shaped chute and basin was under consideration

at the time of initiation of the model study because of the saving in reinforcing steel which would be effected. This saving was desirable because of the cost involved and also because materials were difficult to procure. Instead of restraining the adjacent earth cuts by means of heavy, reinforced, gravity-type vertical walls, it was planned that the surface to be lined would be graded to slopes that would be stable without reliance for stability upon the concrete lining.

33. The first tests of the stilling basin as originally designed indicated that it would be inadequate as a means of dissipating the energy of flow from the spillway. In order to arrive quickly at a satisfactory stilling-basin design and obviate the laborious process of securing data on designs not worthy of extensive investigation, a series of observation tests was conducted to restrict the field of testing to the more effective basins. Only photographic data are presented on those designs which indicated no improvement. Table 2 contains a detailed description of all the stilling-basin designs investigated during the course of the study.

34. During the testing program the maximum discharge for testing was changed several times. For tests of the original and type 1 designs a discharge of 63,000 cfs was used since that was the spillway capacity near maximum pool level. During tests of the types 2-26 design stilling basins, the type B approach walls were installed, reducing the capacity to about 53,800 cfs. Consequently 53,800 cfs represented the maximum discharge for tests of these basins. The types 27 and 28 designs both involved shorter crest lengths which reduced capacity flow of these two designs to 51,800 and 40,600 cfs, respectively. For tests of the types 29-38 designs the pool level was disregarded and a flow of 50,000 cfs

was used, closely simulating the maximum design outflow of 49,700 cfs desired. In comparing the results of the stilling-basin tests, consideration should be given to the discharge involved in each case.

Description -- original design

35. The stilling basin as originally designed consisted of a 360-ft horizontal apron located at elevation 190. No baffle piers or end sill were placed on the apron, although it was anticipated that their need would be demonstrated by the model tests. Flow through the stilling basin was confined by 1-on-2 sloping side walls. The bottom width of the stilling basin was 200 ft, whereas at the minimum tailwater elevation of 220.4 ft for 50,000 cfs the top width of the basin was 322.4 ft. Investigation of the original basin design was confined to observing and photographing flow conditions.

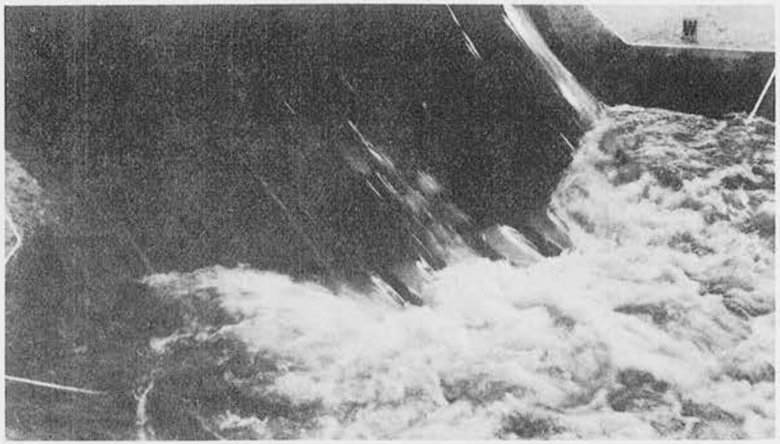
Results -- original design

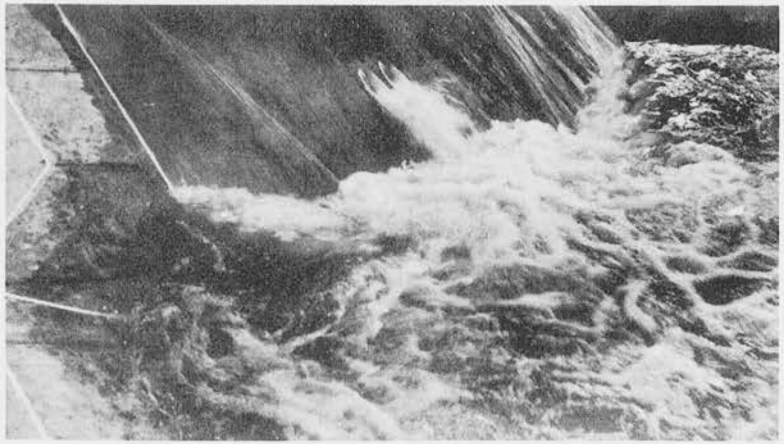
36. Observation of flow conditions in the stilling basin, as originally designed, revealed that basin action was unsatisfactory for all discharges. Figure 7 demonstrates that flow from the chute at both high and low discharges was concentrated in a narrow portion of the basin width as a result of the large eddies formed at the junction of the chute and stilling-basin walls. Although the walls of the chute and stilling basin were on the same slope (1 on 2) and the toes of the chute and basin side-walls were on a line parallel with the centerline of the spillway, the junction of the sloping chute and horizontal basin formed a reentrant angle in the wall on either side (see figure 2). This reentrant angle caused eddies which crowded the chute flow into a small

Original design.

Discharge 63,000 cfs; tailwater elev. 223.8

Discharge 20,000 cfs; tailwater elev. 215.0





Type 1 design.

Discharge 63,000 cfs; tailwater elev. 223.8

Discharge 20,000 cfs; tailwater elev. 215.0

Figure 7. Hydraulic performance of original and type 1 basin designs at high and low flows

portion of the basin width. Although the flow from the chute into the basin was confined to a small portion of the basin width, the location of the confined path of flow varied at intervals from the left wall of the basin to the right wall and then again to the left. Even with an apron length of 360 ft the exit channel was subjected to high-velocity currents which extended through the basin and attacked the unpaved portion of the exit channel.

Description -- type 1 design

37. In an attempt to improve the performance of the basin as originally designed, dentates were added at the toe of the chute. These dentates were 10 ft high, 10 ft wide, 45 ft long, and were spaced at about 10 ft. Those near the side walls were placed at a slight angle to the spillway centerline in an attempt to force the greater percentage of flow along the basin walls and thus destroy or reduce the side eddies at the junction of the chute and basin walls.

Results -- type 1 design

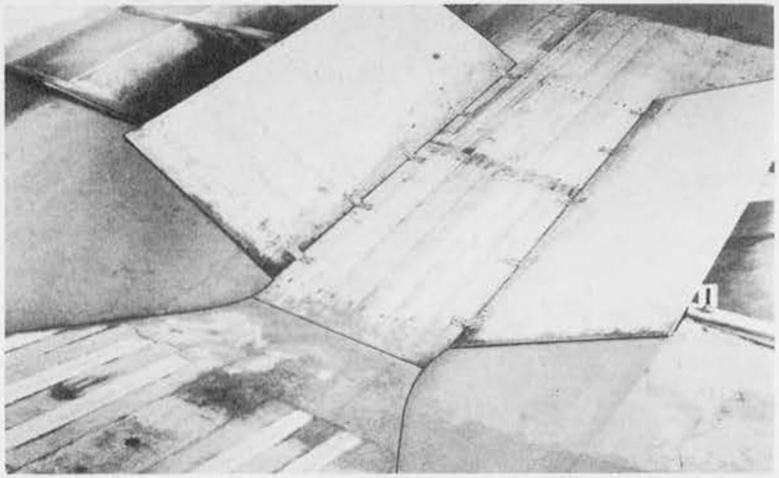
38. As shown in figure 7 the addition of the 10-ft dentates at the toe of the chute aided only slightly in improving flow distribution in the basin. At high discharges the flow from the chute forced the tailwater downstream, exposing part of the dentates and thus permitting them to deflect part of the chute flow. At low discharges, however, the dentates were entirely submerged and had no apparent effect on flow. For all conditions of discharge, flow was concentrated in a small portion of the basin with strong upstream currents in the areas adjacent to the side walls.

Description -- types 2-5 designs

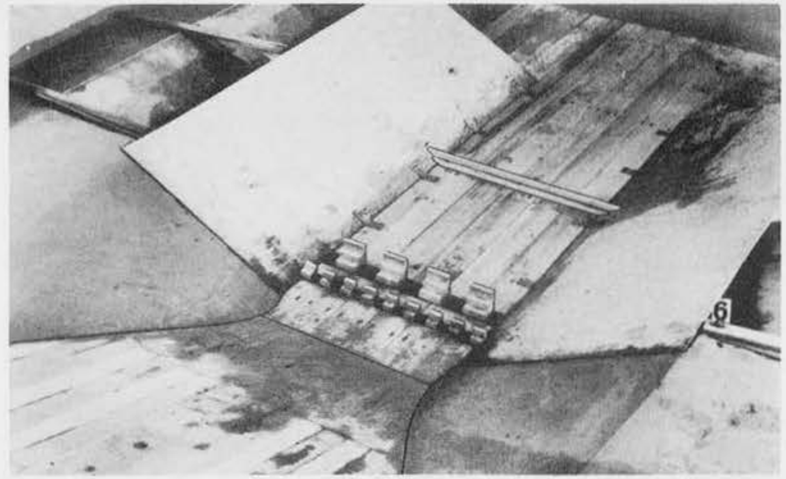
39. Since the dentates alone were unsuccessful in improving flow conditions in the basin, the types 2-5 designs incorporated more extensive alterations. In an effort to eliminate the eddies, the stilling basin was narrowed to such an extent that the path of flow along the stilling-basin walls was an extension of the path of flow adjacent to the chute walls. This was accomplished by reducing the apron width at the base of the side walls from 200 to 84 ft and placing transition walls from the chute to the basin. The reduced basin width was common to the types 2-5 designs, while the addition of baffle piers, end sill, dentates, and a solid stepped bucket formed the various other alterations investigated in these designs as illustrated by figure 8. Details of the designs are listed in table 2.

Results -- types 2-5 designs

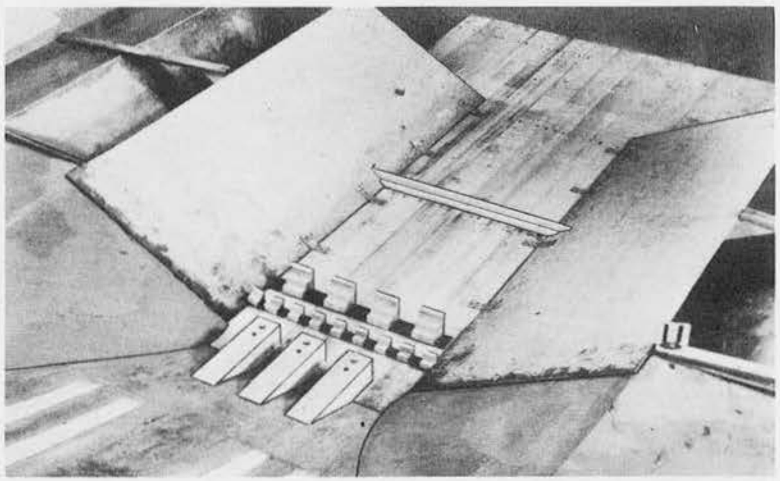
40. Observation of flow conditions (see figure 9) with the types 2-5 designs in place revealed unsatisfactory basin performance for each design at high discharges. In the type 2 design the reduction in basin width caused excessive turbulence in that area, and the partial jump which formed over the apron was almost forced from the basin unless baffle piers and an end sill were used as in the type 3 design. These alterations eliminated some of the turbulence, but basin conditions were still poor. The addition of dentates or a solid stepped bucket at the toe of the chute (types 4 and 5 designs) caused the jump to be swept into the exit channel and resulted in very unstable basin action. At low discharges, flow conditions with the types 2, 3 and 4 designs were



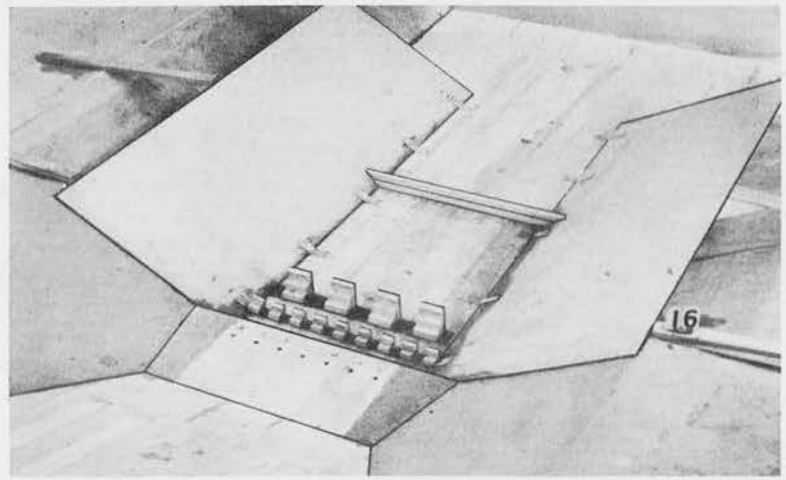
Type 2 design



Type 3 design

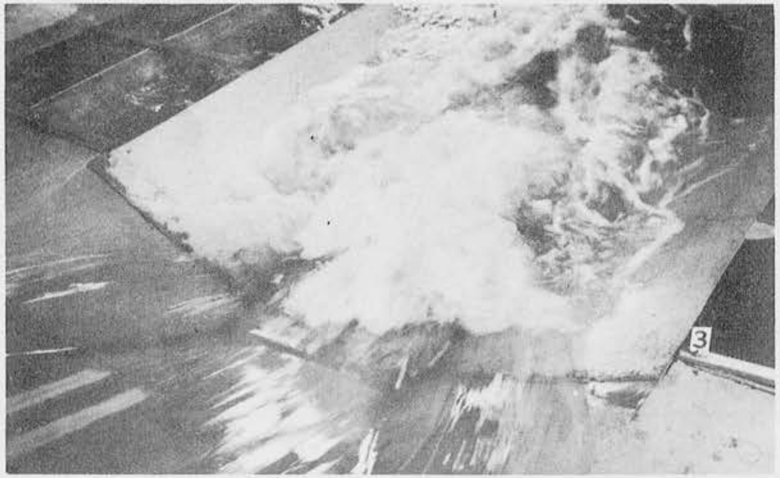


Type 4 design

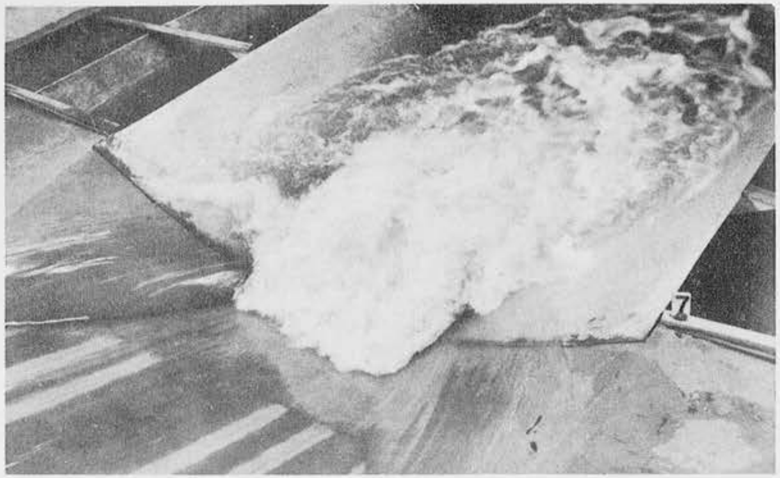


Type 5 design

Figure 8. Basin designs tested with apron narrowed to 84 ft (types 2-5)

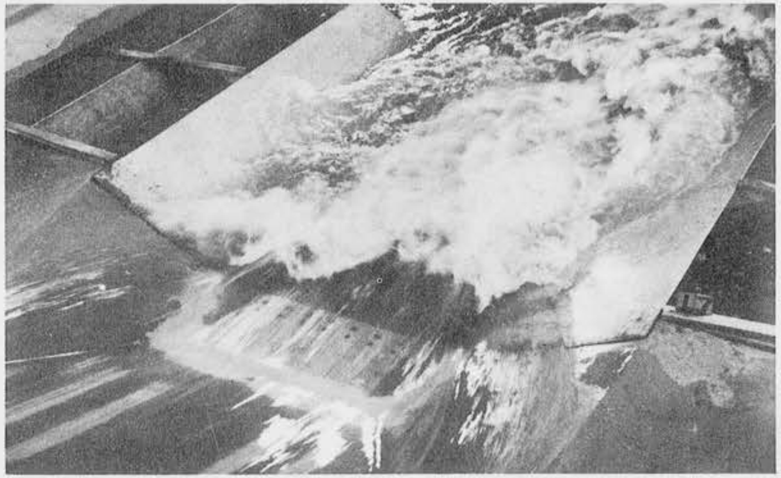


Type 2 design



Type 3 design

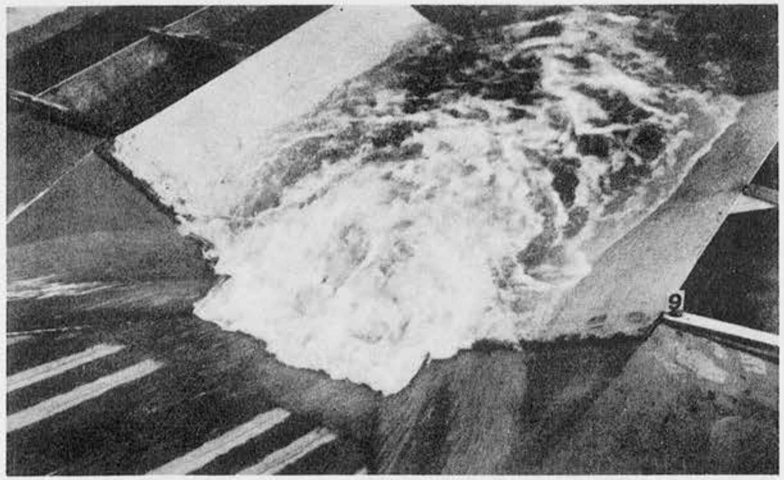
Type 4 design



Type 5 design

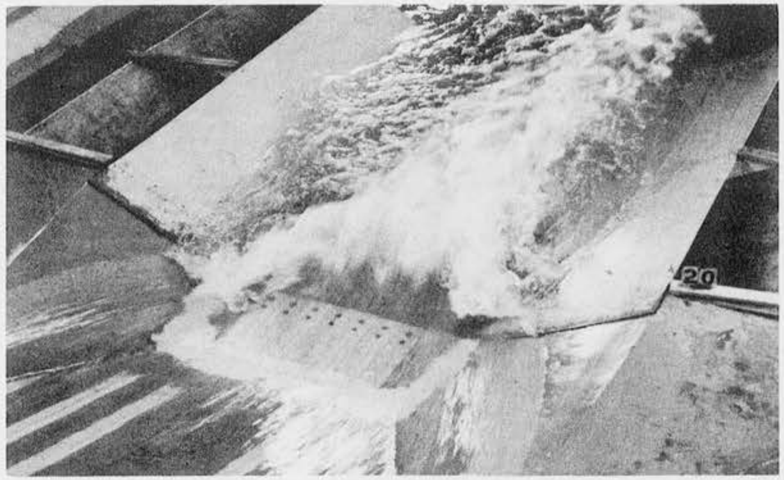
Figure 9. Hydraulic performance of types 2-5 basins at high flows. Discharge 53,800 cfs; tailwater 221.7

Type 2 design



Type 3 design

Type 4 design



Type 5 design

Figure 10. Hydraulic performance of types 2-5 basins at low flows. Discharge 25,000 cfs; tailwater 216.0

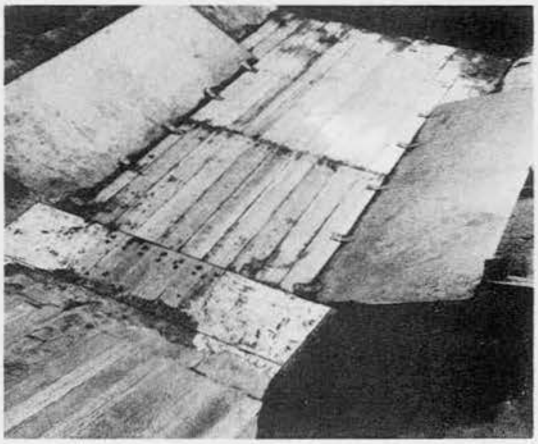
improved in that a fair hydraulic jump formed within the confines of the basin, as shown in figure 10. The use of a solid stepped bucket of the type 5 design, however, prevented the formation of a jump at low flows. Although basin action was satisfactory at low discharges for types 2, 3 and 4 designs, the unsatisfactory performance of all four basins at high discharges eliminated them from further consideration.

Description -- types 6-11 designs

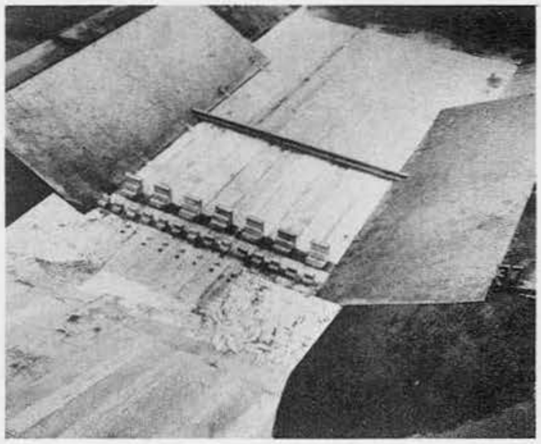
41. Inasmuch as tests of the types 2-5 designs had demonstrated that the 84-ft basin width was too narrow, this width was increased to 144 ft and basin elements similar to those tested in the types 2-5 designs were investigated with the new basin width. Details of these designs are listed in table 2 and illustrated by figure 11.

Results -- types 6-11 designs

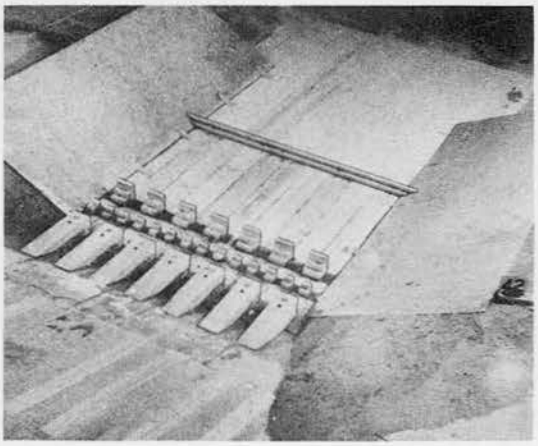
42. Flow conditions with the types 6-11 designs are shown by figures 12-13. It was observed that flow conditions with the types 6 and 7 designs installed were similar to those for the type 5 design previously discussed in that the 10-ft step or drop at the toe of the chute caused the jump to be swept from the stilling basin at all discharges. Of the designs tested in this group the types 8 and 11 induced the most satisfactory conditions. At high discharges the flow was violent and unstable; at low flows, although the 10-ft dentates of type 8, and the 5-ft step of type 11 design did not entirely eliminate the side eddies at the chute and basin wall junction, the eddies were reduced in size. Comparison of flow conditions of the type 8 and 11 designs with those of the types 9 and 10 designs clearly indicate the need for baffle piers,



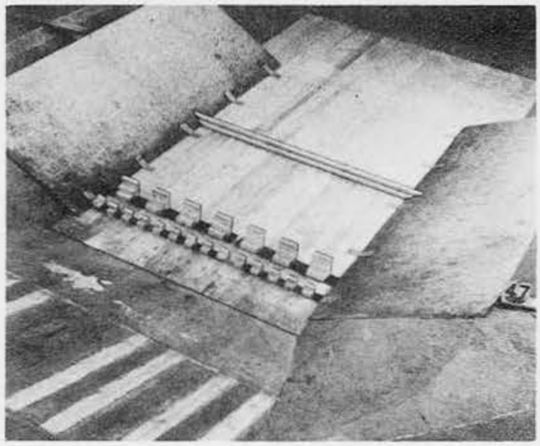
Type 6 design



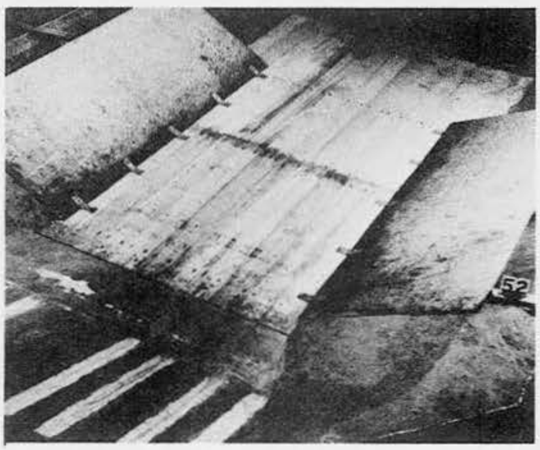
Type 7 design



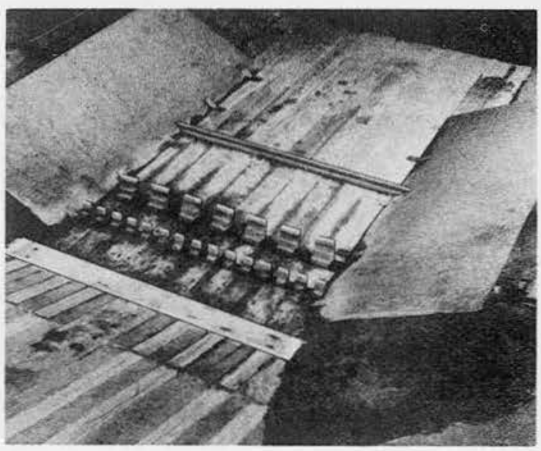
Type 8 design



Type 9 design



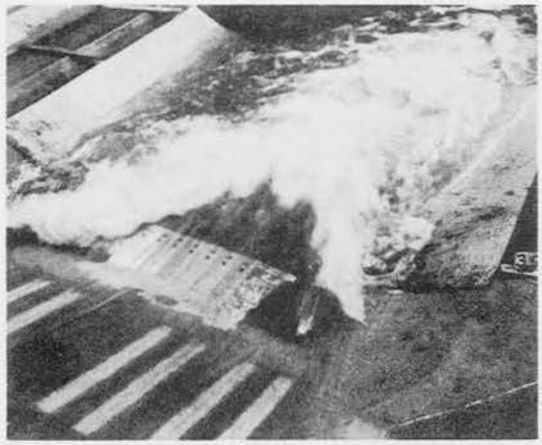
Type 10 design



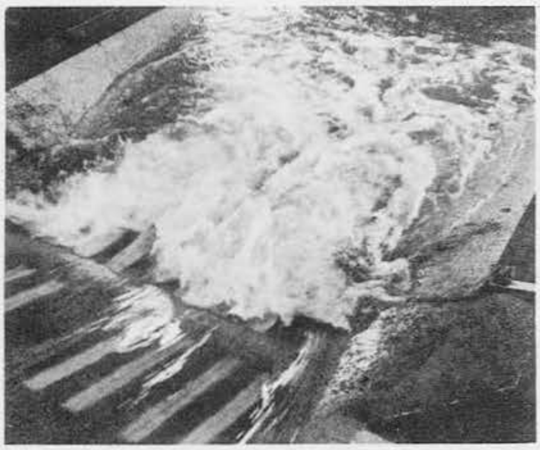
Type 11 design

Figure 11. Basin designs tested with apron width of 144 ft (types 6-11)

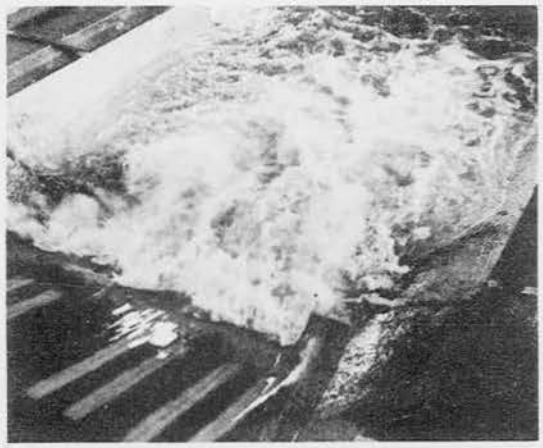
Type 6 design



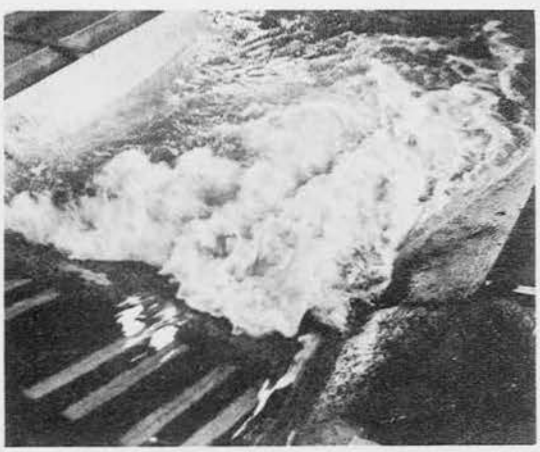
Type 7 design



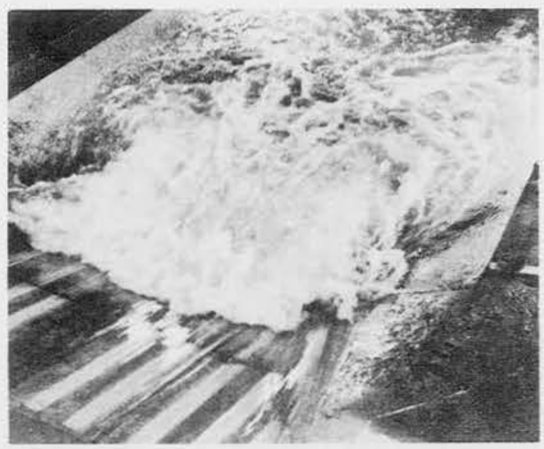
Type 8 design



Type 9 design

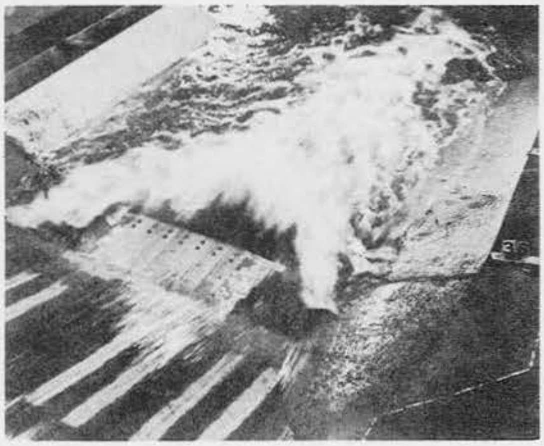


Type 10 design



Type 11 design

Discharge 53,800 cfs; tailwater elevation 221.7
Figure 12. Hydraulic performance of types 6-11 basins at high flows



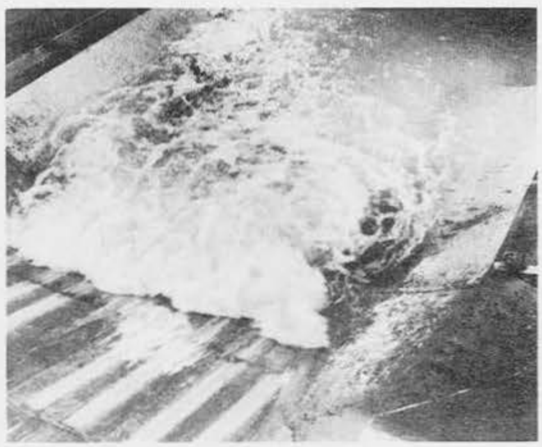
Type 6 design

Type 7 design

Type 8 design

Type 9 design

Type 10 design



Type 11 design

Discharge 25,000 cfs; tailwater elevation 216.0
Figure 13. Hydraulic performance of types 6-11 basins at low flows

end sill, and some additional structures at the toe of the chute to aid in spreading the flow across the full width of the basin. Analysis of all previous observation tests confirmed this conclusion. With the type 11 basin installed and at a discharge of 53,800 cfs, velocity distributions were measured at the end sill to determine whether any high concentrations of flow existed over the end sill. The bottom velocities over the end sill were evenly distributed and in the range of 2 to 4 ft per sec (see plate 9).

Description -- type 12 design

43. The type 12 design incorporated the structural features which were shown by previous observations to be needed at the toe of the chute to spread the flow in the basin, and in addition included a new design for the face of the chute. The basin design consisted of the originally favored 200-ft width, a 150-ft length, two rows of baffle piers 8 and 12 ft in height, respectively, and a 5-ft end sill. The chute had a slope of 1 on 4 from the invert of the conduit exit portals to a 10-ft-high stepped bucket at its toe, while the original chute slope of 1 on 3 was maintained adjacent to the chute walls, forming a 15-ft wide depressed channel on each side of the chute. The purpose of the channels was to increase the amount of flow adjacent to each wall in an effort to destroy the eddies previously described.

Results -- type 12 design

44. The type 12 design was unsuccessful in accomplishing its purpose due to the fact that the depth of the small channel adjacent to each side wall was insufficient to pass the amount of flow necessary to

eliminate or reduce eddy action within the basin.

Description -- types 13-15 designs

45. In the types 13, 14 and 15 stilling-basin designs, the use of a chute with an arched floor surface was introduced to aid in securing uniform flow distribution in the stilling basin. Beginning 12 ft downstream from the spillway crest, the elevation of the chute floor at the centerline was raised 6.7 ft for the type 13 design and 3.3 ft for the types 14 and 15 designs. In each case the original elevation of the chute at the side walls was maintained. The type 15 design comprised, in addition to the arched chute, a 5-ft solid stepped sill at the toe of the chute and a 10-ft deflector pier on either side of the chute at the entrance to the stilling basin. In all three designs one row of 8-ft baffle piers, one row of 12-ft baffle piers, and a 5-ft end sill were placed on the 150-ft apron to aid in the dissipation of energy. The basin width in each design was 200 ft. Details of the type 14 design are shown by figure 14.

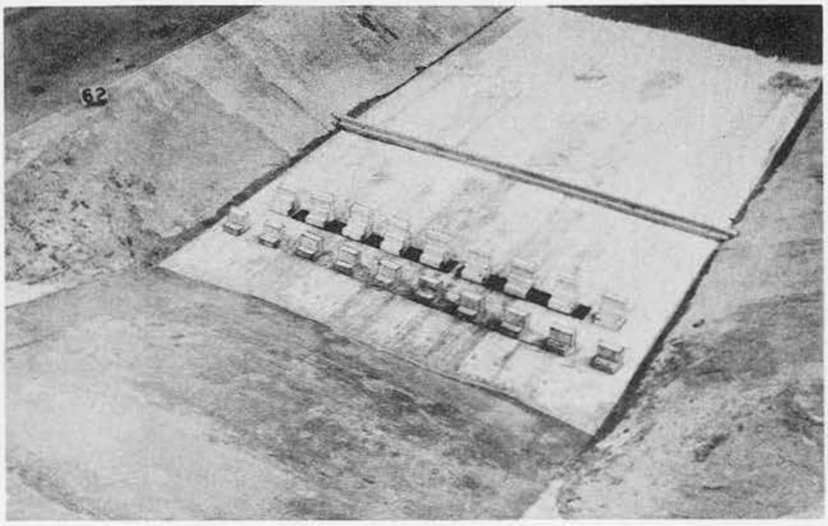
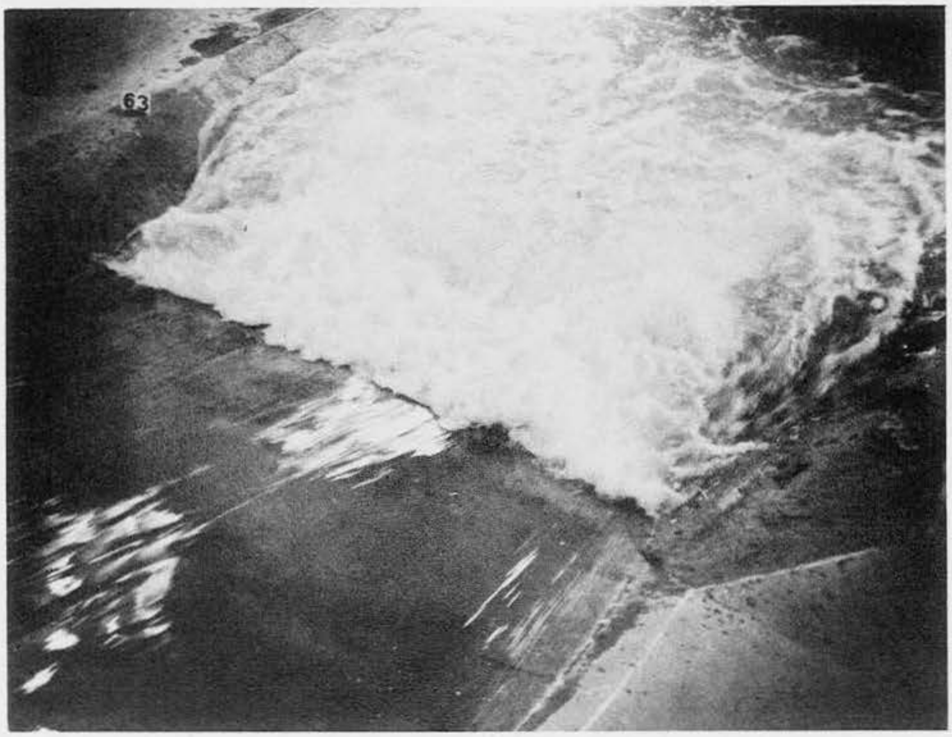


Figure 14. Type 14 design with arched chute and original basin width

Results -- types 13-15 designs

46. The use of the arched chute of type 13 design gave excellent flow distribution at high discharges. The eddies formerly existing at the side walls were almost eliminated and a good jump formed over the basin width. At low flows, however, the arched chute caused most of the flow to be concentrated along the sides of the basin. Consequently, for low discharges the flow in the basin was swift adjacent to the walls and was directed upstream at the center of the basin. Since unfavorable conditions existed at normal flows, it was decided that the centerline of the chute had been elevated too much. This decision was confirmed by the improved conditions which prevailed when the type 14 design, with its 3.3 ft rise at the centerline, was tested. As shown by figure 15, the eddies adjacent to the walls, though not eliminated entirely, were greatly reduced in size and did not interfere appreciably with jump action. Velocities measured over a cross section of the basin at the end sill indicated fairly uniform flow distribution (see plate 9); the maximum bottom velocity recorded over the end sill was only 6 ft per sec. The solid stepped sill and deflectors of the type 15 basin were intended to eliminate the small eddies still existing with the type 14 design without interfering with jump action. Flow conditions were not enough improved, however, to warrant construction of the extra sill and deflectors. The most important fact demonstrated by tests of the types 13-15 designs was that good basin conditions could be obtained through use of an arched chute floor. The results of tests with the type 14 design indicated it to be the best of the first fifteen designs investigated.



Discharge 53,800 cfs; tailwater elevation 221.7

Discharge 25,000 cfs; tailwater elevation 216.0

Figure 15. Hydraulic performance of type 14 basin at high and low flows

Description -- type 16 design

47. The type 16 design was similar to the type 15 design except that the chute was restored to its original plane surface. The purpose of tests of the type 16 design was to investigate the possibility of spreading the chute flow entirely by structures located on the chute. Therefore, in addition to the 8- and 12-ft baffle piers and the 5-ft end sill on the horizontal apron, 10-ft triangular deflector blocks* were placed on the chute immediately upstream from its junction with the basin.

Results -- type 16 design

48. The type 16 design gave fair basin action at all discharges. The flow striking the large blocks was deflected at an angle directly into the areas formerly occupied by eddies. The direction of flow destroyed the eddy action and permitted a good jump to form. The only undesirable feature of the design was that the high-velocity flow adjacent to the side walls tended to extend into the exit channel.

Description -- types 17-27 designs

49. In view of the fact that previous tests had indicated that, with a trapezoidal-shaped basin, arching of the chute surface or use of high deflector blocks on the chute were the only improvements worthy of further consideration, it was thought desirable to investigate a few designs with vertical basin walls to obtain comparative data on the

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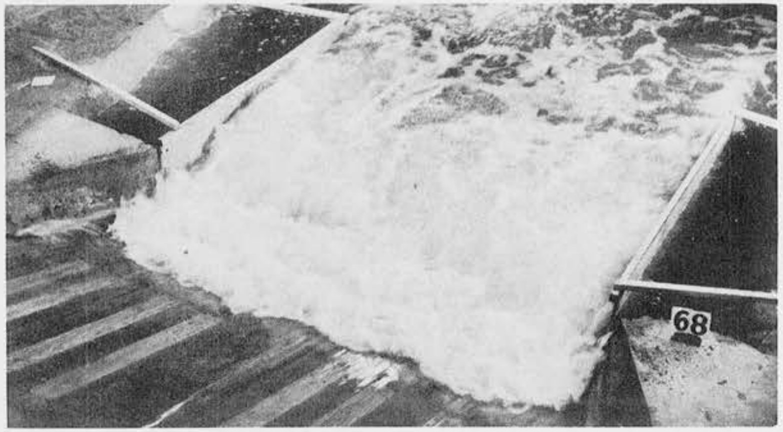
* Deflectors of this type were used on all basin designs incorporating deflectors. For details see figure 19 and plate 32.

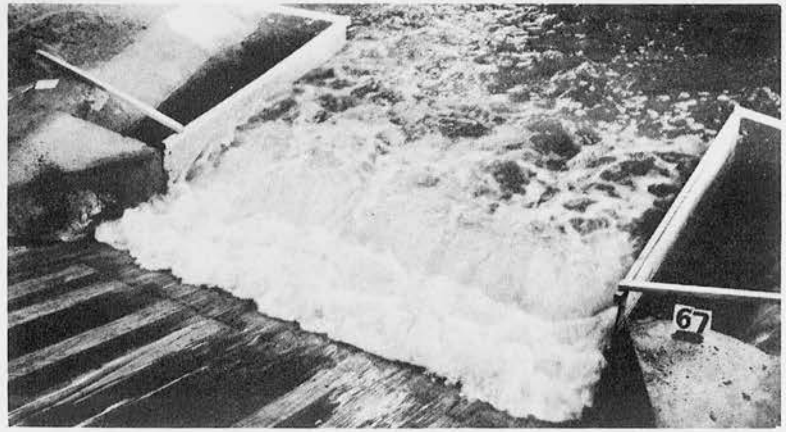
relative effectiveness of trapezoidal- and vertical-shaped stilling basins.

50. Accordingly, the types 17-27 designs consisted of vertical basin walls, 150-ft apron length, and a 200-ft basin width, with differences in the various designs involving mainly the height and location of baffle piers. In all designs of this group, except the type 27 design, the chute walls retained their original 1-on-2 slope with a transition to vertical walls provided at the junction of the chute and stilling basin. In the type 27 design, vertical walls were maintained for the full spillway and basin length in order to compare the effects of vertical and sloping chute walls. Reference is made to table 2, which lists the detailed dimensions of each basin element. Reference is also made to paragraphs 68 and 69 for discussion of two additional vertical-wall type stilling basins.

Results -- types 17-27 designs

51. As shown by figure 16, the use of vertical stilling-basin walls improved flow conditions within the basin more than the previously-observed trapezoidal-shaped basin. Moreover, the sloped chute walls with a transition to vertical basin walls were as efficient in providing good basin conditions as were the vertical walls throughout the chute and basin (type 27 design). The use of vertical chute walls in the vicinity of the spillway crest section (type 27 design) resulted in a reduction in effective crest length, and a slight decrease in spillway discharge. Observation tests conducted with the type 18 design clearly indicated that the absence of baffle piers caused an unstable condition,

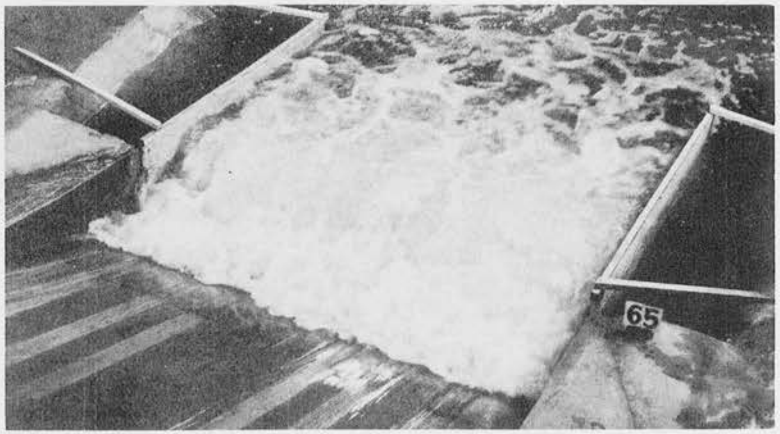


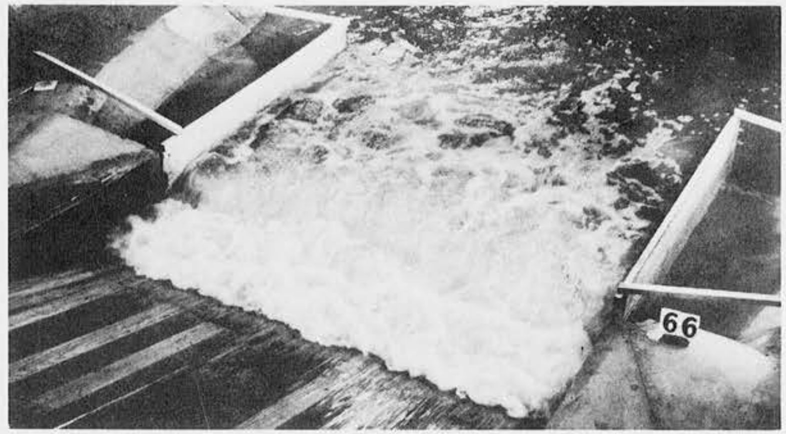


Type 24 design.

Discharge 53,800 cfs; tailwater elev. 221.7

Discharge 25,000 cfs; tailwater elev. 216.0





Type 27 design.

Discharge 51,800 cfs; tailwater elev. 221.7

Discharge 25,000 cfs; tailwater elev. 216.0

Figure 16. Hydraulic performance of types 24 and 27 basins at high and low flows

bordering on spray action, to exist in the basin. The addition of baffle piers stabilized jump action, although when placed near the toe of the chute, the piers were subjected to considerable impact. Water-surface profiles recorded on the centerline of the spillway with the type 25 design installed indicated that flow over the spillway was smooth and a good hydraulic jump was formed in the stilling basin (see plates 12 and 13). Velocity distributions measured over the end sill with the type 25 design installed indicated an even distribution of flow in the exit channel; the maximum bottom velocity recorded over the sill was 10 ft per sec (see plate 9).

52. Scour tests conducted at a discharge of 53,800 cfs indicated that placing of the baffle piers farther downstream in the type 25 design improved scour conditions over those existing with the type 24 design (see plates 11 and 14). Tests of basin action with the end sill and baffle piers removed (type 26 design) clearly indicated the need for these elements, as the jump was formed 90 ft below the toe of the chute and extended into the exit channel, thereby causing excessive scour (see plate 17).

53. Of the vertical-wall type designs tested, the best all-round basin performance was secured with the type 25 design. The 6-ft baffle piers were placed far enough downstream from the toe of the chute to be cushioned against excessive impact forces, yet they aided in stabilizing the jump and deflecting high-velocity bottom currents upward away from the bed of the exit channel. Bottom velocities measured in the exit channel, and shown on plates 15 and 16 for discharges of 53,800 cfs and 25,000 cfs, were negligible.

Description -- type 28 design

54. The type 28 design was developed by combining several alterations suggested by the Harza Engineering Company. Details of this design are shown on plate 18. In order to spread the flow, the floor of the chute was not only arched, being 3.3 ft higher on the centerline, but was also flared in plan. The chute started from a concave-shaped crest 160 ft in width, and flared to 200 ft near its intersection with the basin, then returned to a 160-ft basin width. As suggested by the Harza Engineering Company, the basin was 265 ft long and contained two rows of 6-ft baffle piers and a 5-ft end sill. The 160-ft concave-shaped crest was designated as the type C approach.

Discharge 40,600 cfs; tailwater elevation 218.3

Figure 17. Hydraulic performance of type 28 basin at high flow

Results -- type 28 design

55. Flow conditions observed with the type 28 design installed were not as good as those observed with other type designs. The maximum discharge that could be passed over the narrowed crest was only about 40,600 cfs at the maximum pool level, which is less than the discharge of 49,700 cfs desired. The head-discharge curve established for the type C approach is plotted on plate 5. At the maximum discharge of 40,600 cfs, flow tended to cling to the left portion of the basin with a strong upstream current adjacent to the right wall (see figure 17). The velocity distribution measured in a vertical plane over the end sill indicated that the highest velocities were located near the left wall and reached a magnitude of 8 ft per sec over the end sill (see plate 9).

Description -- types 29-33 designs

56. Inasmuch as the type 14 design with its arched chute as described in paragraphs 45 and 46 had performed so well, it was decided to study refinements in the dimensions of the various elements of this design. The types 29-33 designs had an arched chute with a rise of 5.12 ft at the centerline sloping down to the original elevation at the sides. The 5.12-ft rise at the centerline was selected because tests of the type 13 design had indicated that a rise of 6.7 ft was too high for good flow conditions at low discharges, and it was believed that the rise of 3.3 ft tested in the type 14 design was too low for best performance at high discharges. The type 29 design included a 150-ft apron without baffle piers, whereas in the types 30, 31, 32 and 33 designs the apron length was 100 ft; variations consisted of no baffle piers, one row of

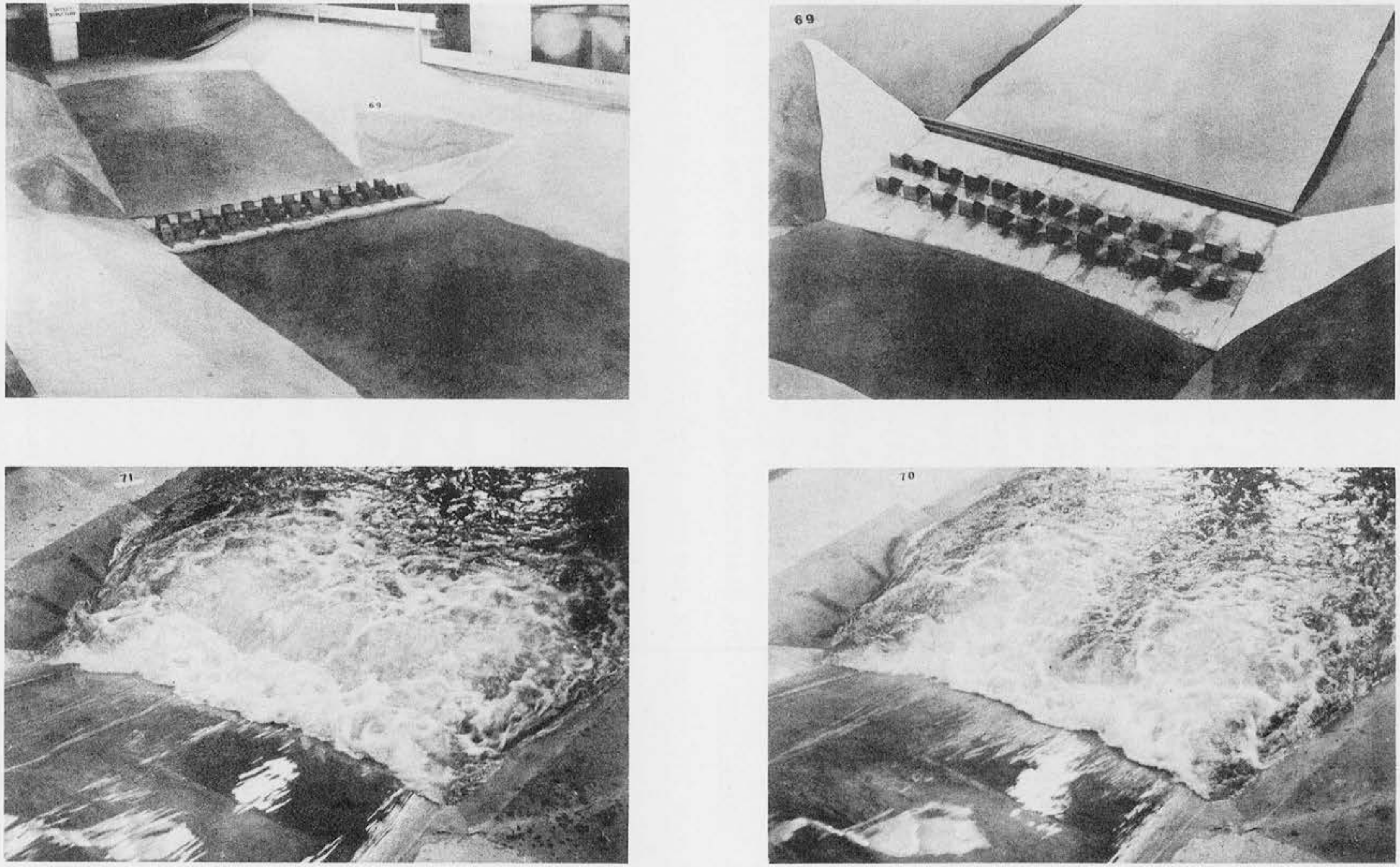
8-ft baffle piers, two rows of 8-ft baffle piers, and two rows of 6-ft baffle piers, respectively (see table 2). Details of the type 32 design are shown by figure 18 and plate 24.

Results -- types 29-33 designs

57. Flow conditions. Flow conditions in the basins of types 29 and 30 designs were very unstable, with large eddies adjacent to each basin wall. The addition of one row of baffle piers (type 31) improved flow conditions, though the piers apparently were subjected to severe impact. It was not until the two 8-ft rows of baffle piers were added (type 32 design) that good flow conditions were obtained (see figure 18). At a discharge of 50,000 cfs the flow was distributed evenly across the basin, forming a good jump. Although small eddies still existed at the extremities of the jump, they were not believed to be detrimental to basin performance. At a discharge of 25,000 cfs, jump action was good, though not quite as good in the center portion of the basin as at higher discharges.

58. Water-surface profiles. Water-surface profiles recorded on the centerline of the spillway and adjacent to one of the chute walls show the configuration of the jump in the type 32 basin. These data also demonstrate the effect of the arched chute, in that the water-surface level is higher in the center portion of the spillway than adjacent to the chute walls (plates 25-26).

59. Scour. Measurements of scour with the types 29 and 30 designs installed (plates 19-22) indicated that the apron length of 150 ft used with the type 29 design offered only slightly more protection to



Discharge 50,000 cfs; tailwater elevation 220.6

Discharge 25,000 cfs; tailwater elevation 216.0

Figure 18. Elements of type 32 basin design, and hydraulic performance at high and low flows

the bed of the exit channel than the 100-ft apron of the type 30 design. It was therefore decided that an apron length of 100 ft was sufficient. Scour data also indicated that less erosion occurred in the exit channel for a discharge of 50,000 cfs than for a 25,000 cfs discharge. This was due to the better flow conditions existing in the stilling basin and exit channel at the higher discharge. Addition of one row of 8-ft baffle piers (type 31 design) on the 100-ft apron effected a large reduction in the amount of scour as illustrated by a comparison of plates 21 and 23. The use of two rows of 8-ft baffle piers (type 32 design) reduced the amount of scour still further (plates 27 and 28). As shown by plate 31, a reduction in the height of both rows of baffle piers from 8 to 6 ft (type 33 design) resulted in a very slight increase in the depth of scour.

60. Velocities. The distribution of velocities at the end sill for the types 29, 30 and 32 designs, is plotted on plates 9 and 10 and indicates the necessity for baffle piers to obtain even flow distribution into the exit channel. When the baffle piers were omitted as in the types 29 and 30 designs, high velocities were concentrated near the side walls of the basin. With the baffle piers of the type 32 design installed, however, velocities were uniformly distributed across the end sill and were small in magnitude -- the maximum velocity immediately over the end sill did not exceed 8 ft per sec. Bottom velocities over the exit area also were measured at discharges of 50,000 cfs and 25,000 cfs with the type 32 design in place. As shown by plates 29 and 30, velocities in the exit area ranged from 1 to 11 ft per sec at a discharge of 50,000 cfs and from 1 to 4 ft per sec at a discharge of 25,000 cfs. The higher velocities were recorded adjacent to the riprapped sections

on the sides of the exit channel, and were due in part to the fact that the cross section of the exit channel was a continuation of the cross section of the stilling basin.

Description -- type 34 design

61. The type 34 design was developed as a result of observation tests of the elements of type 16 design. In these tests the use of high deflector blocks located on either side of the flat chute of the original design had given promise of providing good basin action. Details of the type 34 design are shown in table 2, and by figure 19 and plate 32. The design incorporated two 15-ft high streamlined deflector blocks on the chute as well as two rows of 8-ft baffle piers, and a 5-ft end sill on a 100-ft apron.

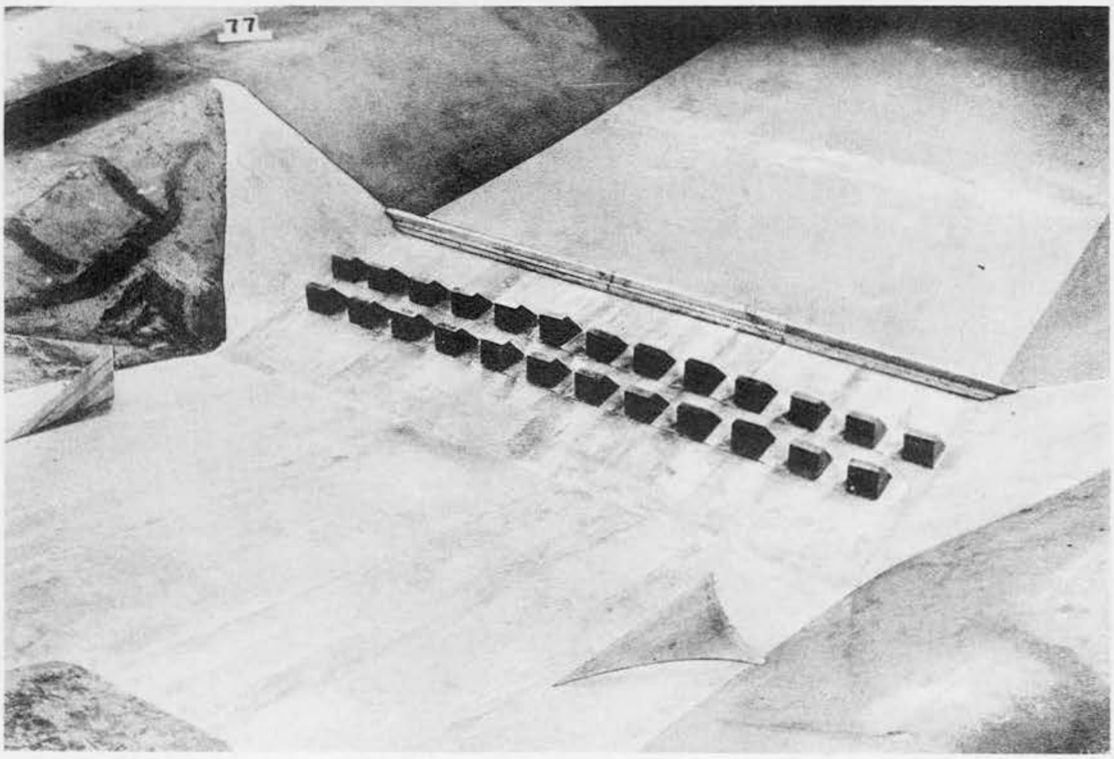


Figure 19. 15-ft deflector blocks on flat chute of type 34 design

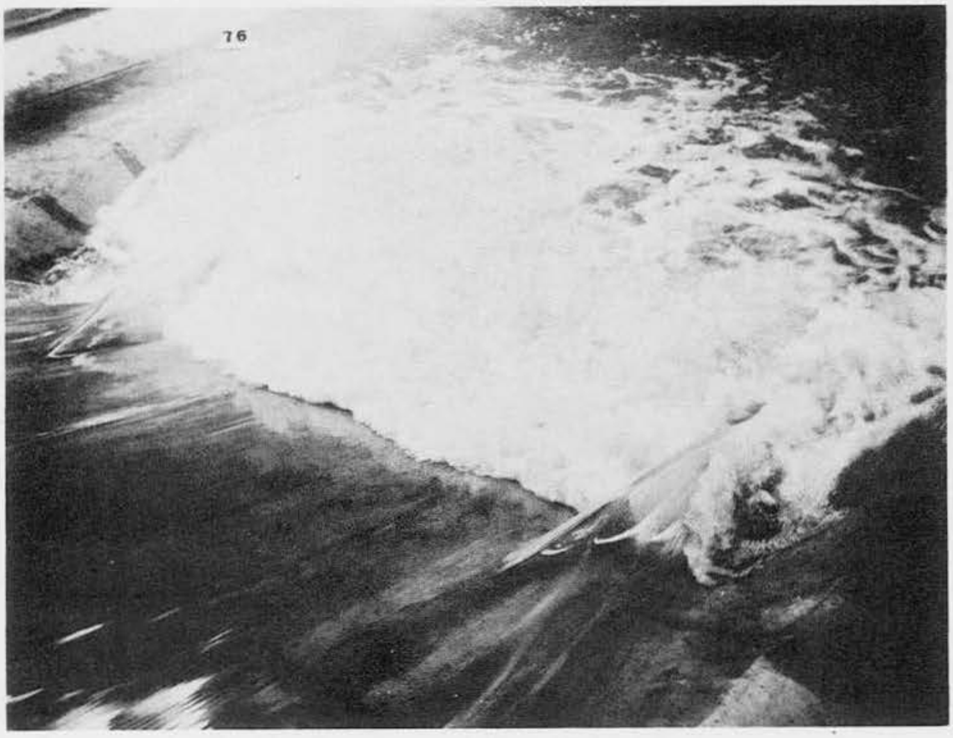
Results -- type 34 design

62. Flow conditions. Flow conditions in the type 34 basin were satisfactory. The 15-ft deflectors were sufficiently high to deflect enough chute discharge to break up the eddies adjacent to each basin wall (figure 20). At a discharge of 25,000 cfs, the concentration of flow along the basin side walls caused currents as swift as for a discharge of 50,000 cfs.

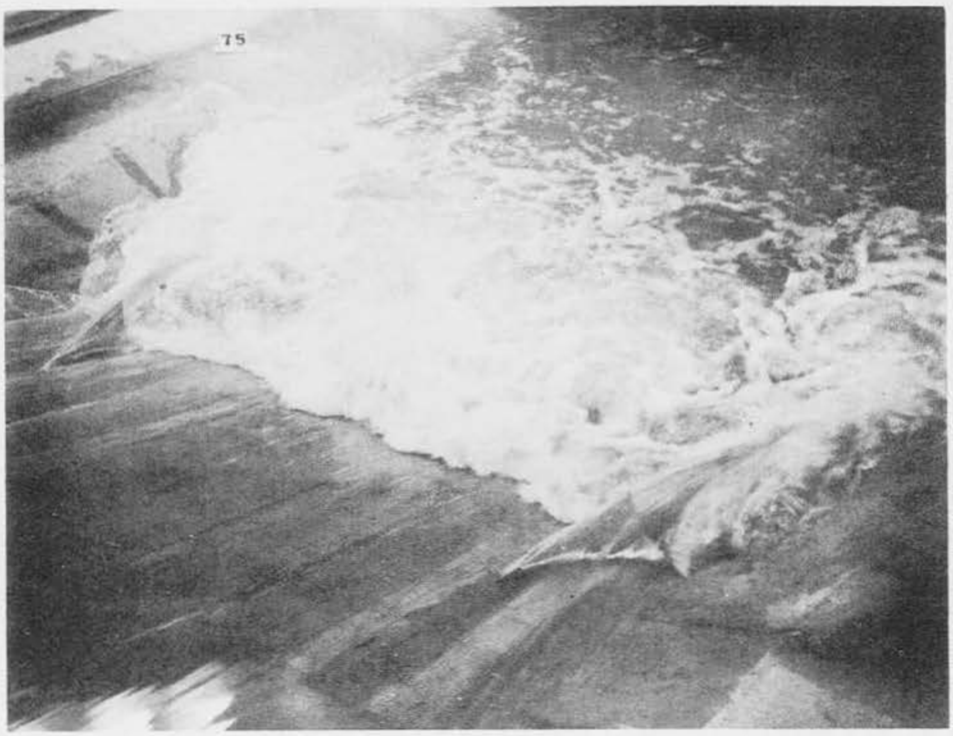
63. Water-surface profiles. Average water-surface profiles measured during tests of the type 34 basin indicated that a good jump was formed at discharges of 50,000 and 25,000 cfs (plates 33 and 34).

64. Scour. Reference is made to plates 35 and 36 showing results of scour tests conducted for discharges of 50,000 and 25,000 cfs. Comparison of these data with results obtained with the arched chute of the type 32 design (plates 27 and 28) indicates that these types were almost equally effective in the dissipation of energy.

65. Velocities. The distribution of velocities in a vertical range at the end sill, and the bottom velocities in the exit channel, are shown on plates 10, 37 and 38. Bottom velocities at the end sill were evenly distributed, and did not exceed 6 ft per sec. Bottom velocities recorded in the exit channel ranged from 1 to 17 ft per sec at a discharge of 50,000 cfs, and from 3 to 14 ft per sec at a discharge of 25,000 cfs. Comparison of bottom velocities with those observed in the exit channel below the basin of type 32 design (plates 29 and 30) indicates that type 32 is the better design, especially at the 25,000 cfs discharge.



Discharge 50,000 cfs; tailwater elevation 220.6



Discharge 25,000 cfs; tailwater elevation 216.0

Figure 20. Hydraulic performance of type 34 basin at high and low flows

Description -- type 35 design

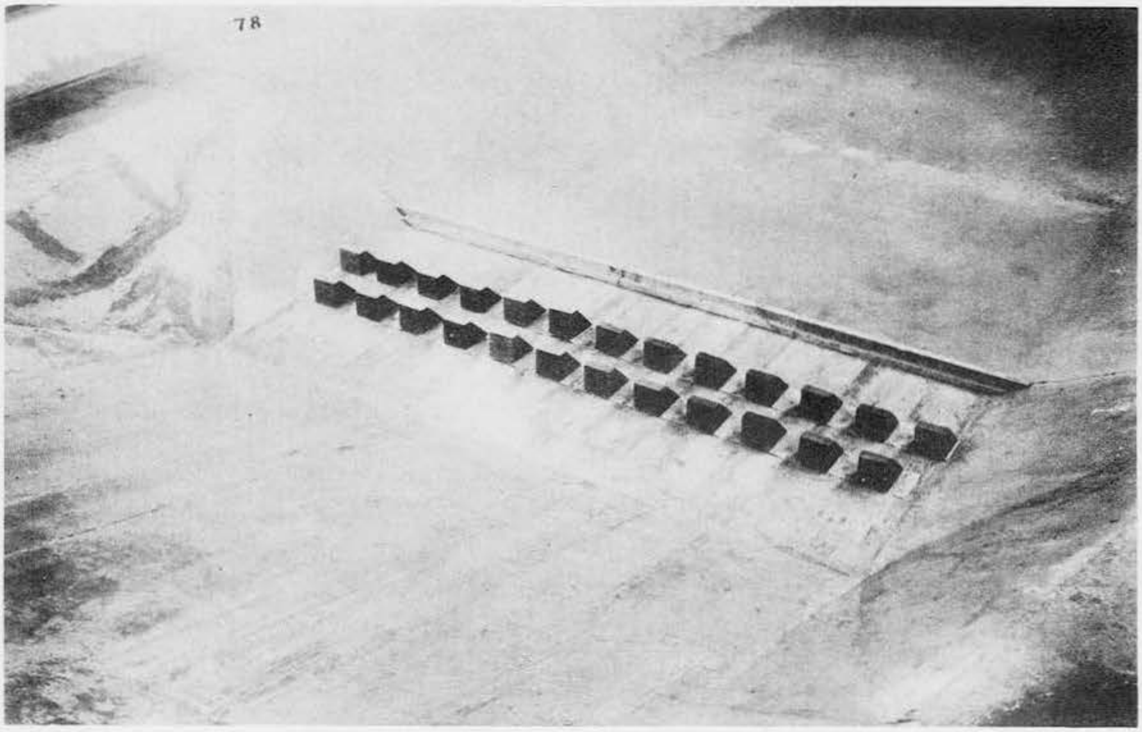
66. The type 35 design is identical to the type 34 design except that the deflector blocks were removed from the chute (table 2 and figure 21). Tests were conducted to study the effect of removing the deflectors.

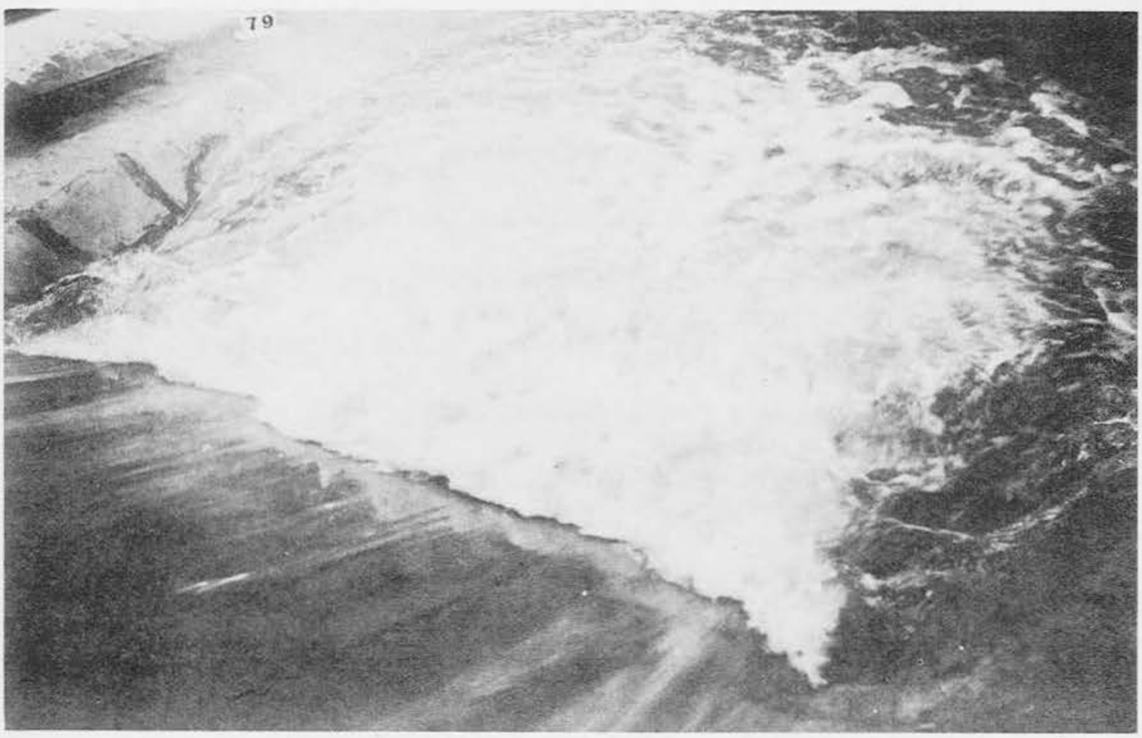
Results -- type 35 design

67. The elimination of the deflector blocks of the type 34 design destroyed the good basin action that had previously prevailed. Large eddies were present at each wall and the chute flow was crowded into a narrow portion of the basin width (figure 21). A scour test conducted at a discharge of 50,000 cfs indicated that scour was excessive, thus showing that the successful performance of the type 34 design was contingent upon the use of the chute deflector blocks (compare plates 35 and 39).

Description -- types 36 and 37 designs

68. A detailed comparison of all test results with sloped and vertical basin walls heretofore described indicates that, although flow conditions in the vertical-walled basin were superior to those existing when sloping walls were used, the amount of scour and distribution of velocities were about the same. Accordingly, the types 36 and 37 designs with vertical side walls were developed for direct comparison with types 32 and 34 designs having sloping side walls. The types 36 and 37 designs involved an apron length of 100 ft, two rows of 8-ft baffle piers, and a 5-ft end sill. The location and size of basin elements were identical to those of types 32 and 34 designs. The only





Discharge 50,000 cfs; tailwater elevation 220.6

Figure 21. Type 35 basin design, and hydraulic performance at high flows

difference between the types 32 and 34 designs was that even distribution of flow into the trapezoidal-shaped stilling basin was secured by an arched chute floor in the type 32 design, and by large deflector blocks in the type 34 design. In the type 37 design the vertical walls of the stilling basin were extended and rounded on a 100-ft radius, whereas in the type 36 design the side walls were terminated at the end sill. In each design the chute walls were on a 1-on-2 slope, with a transition from the chute to the vertical basin walls.

Results -- types 36 and 37 designs

69. Elimination of the sloping side walls of the stilling basin permitted formation of a good hydraulic jump which was evenly distributed across the basin. Flow over the end sill also appeared to be uniformly distributed. Scour tests conducted at a discharge of 50,000 cfs with the types 36 and 37 basins in place indicated that the extension and rounding of the wing walls below the end sill provided some additional degree of protection (plates 40 and 41). Comparison of scour results with those recorded with the type 25 (vertical wall) basin in place (plate 14) indicates that the 50-ft reduction in basin length of the types 36 and 37 designs had little effect. Results of scour tests conducted with the vertical-wall type 37 basin in place (plate 41) and with the sloping-wall basins of types 32 and 34 in place (plates 27 and 35), indicate that no scour occurred with the trapezoidal-shaped basins installed, and only a slight amount occurred in the exit channel below the types 36 and 37 basins.

Description -- type 38 design

70. The type 38 design was evolved at the suggestion of Mr. W. H. McAlpine of the Office, Chief of Engineers, to study the effect of continuing the 5-ft end sill up the 1-on-2-sloping side walls of the stilling basin. All other details of the type 38 design stilling basin were similar to those of the type 32 design, with arched chute, discussed previously.

Results -- type 38 design

71. The extension of the 5-ft end sill up the sloping side walls of the stilling basin had no apparent effect on flow conditions within the basin proper. However, immediately downstream from the end sill on the sloping side walls, small eddies formed which resulted in some erosion; this was not present when the sill was omitted in these areas (compare plates 42 and 43 with plates 27 and 28). Bottom velocities measured in the exit channel were comparable to those measured below the type 32 design. Bottom velocities adjacent to the side walls were slightly higher with the type 38 design as a result of the reduced cross section caused by extension of the end sill (plates 44 and 45). Hence, it can be concluded that the extension of the sill on the sloping side walls of the stilling basin is of no value in improving the safety of the structure.

Summary of Stilling-Basin Test Results

72. Observation tests conducted on the types 1-16 designs indicated that with a trapezoidal-shaped stilling basin design, flow from

the chute had to be redistributed so that the greater portion of the flow entered the stilling basin in the vicinity of the side walls. The additional flow in these areas was necessary to destroy or minimize the eddies formed. It was found by the model tests that the desired distribution of flow could be accomplished only through the use of an arched chute (elevation of centerline increased) or by use of large deflector blocks placed near the toe of the chute and near each confining wall. The observation tests also indicated that even though the arched chute or deflector blocks were used, a more gradual transition from the chute walls to the basin walls was necessary to improve flow conditions within the basin.

73. Tests conducted on the types 17-27 and 36-37 designs were concerned with the determination of the effect of basin elements on flow conditions when vertical basin walls were used. These data were also used as a basis for comparing the effect of sloped walls on stilling-basin performance. Tests indicated that the basin could be shortened if baffle piers and an end sill were used. Comparison of basin performance with sloping and vertical side walls indicated the superiority of the latter insofar as flow conditions within the basin proper are concerned. Both types were about equally effective in protecting the bed of the exit channel from erosion, but velocities along the riprapped sides of the exit channel were higher with the trapezoidal basin than with the rectangular type. The slope of the chute walls had little effect on basin performance when the basin walls were vertical.

74. Analysis of all test results obtained during the course of the model study indicates that the best spillway and basin design, other

than the vertical-wall design, incorporated a chute arched 5.1 ft at the centerline, a 200-ft wide and 100-ft long apron, two rows of 8-ft baffle piers, and a 5-ft end sill (type 32 design). Scour and velocity data recorded on this design indicate it to be safe. The eddies existing at the toe of the chute were still present, although reduced in size.

PART V: SUMMARY OF TEST RESULTS

75. The model study of the spillway for Enid Dam served its purpose in providing the desired information regarding capacity, hydraulic performance, and the effect of sloping side walls on spillway and stilling-basin action. Tests indicated the need for alterations to the approach walls at the spillway crest, and permitted the development of two alternate stilling-basin designs with sloping side walls which gave satisfactory performance. Tests also were conducted on stilling basins with vertical side walls to provide data for comparison of the relative effectiveness of rectangular- and trapezoidal-shaped basins.

76. Model tests to study the capacity of the spillway-crest width as originally designed indicated that at a pool elevation of 283.4 a discharge of 63,000 cfs could be passed. The computed capacity at a pool elevation of 284 was 49,700 cfs. The additional capacity resulted from the increased cross-sectional area provided at the crest by the sloping side walls. Tests also indicated the desirability of extending the slope of the chute walls upstream to intersect the approach walls at or upstream from the crest. This revision (types A or B approach walls), although reducing the crest width, eliminated the standing waves adjacent to each chute wall noted in tests of the walls as originally designed. The reduction in crest width was only about 7 ft and a discharge of 57,000 cfs, which was in excess of the desired capacity, could be passed at a pool elevation of 284.

77. The model study provided valuable information in connection with the design of trapezoidal-shaped stilling basins. The tests

demonstrated the performance of alternate basin designs which, when reviewed from the standpoint of efficiency and economy, formed the basis for selection of a standard rectangular-shaped stilling basin as the final design. In all, 37 alternate stilling-basin designs were investigated.

78. Initial model tests indicated that successful design for a trapezoidal-shaped stilling basin is contingent upon the proper passage of flow from the chute into the stilling basin. The reentrant angles on either side of the stilling basin caused by the intersection of the chute and basin walls prevented the even distribution of flow across the basin; large eddies were formed adjacent to each wall, confining the chute flow to a limited fraction of the total basin width. Attempts to eliminate these eddies and force the formation of the jump by addition of baffle piers, reduction in basin width, and divergence or convergence of chute walls, were unsuccessful. Additional tests indicated that either an arching of the floor of the chute by increasing the elevation along the centerline (type 32 design), or the use of large blocks on the chute near its junction with the basin (type 34 design), were the only plans which would improve basin action. The arching of the chute (type 32 design) forced the areas adjacent to the walls to carry a greater proportion of the discharge, thereby reducing the size of the eddies adjacent to the basin walls. Arching of the chute was started about 12 ft downstream from the spillway crest in order not to reduce the spillway capacity. The large deflector blocks of the type 34 design, placed on the chute about 47.5 ft above the toe of the chute and about 20 ft from the side walls (plate 32), were so shaped as to change

the direction of flow near the chute side walls and to cause it to follow the basin walls. In each of these two designs, side transition walls from the chute to the basin, two rows of baffle piers, and an end sill were also found necessary.

79. Tests conducted with vertical basin walls clearly indicated the superiority of vertical walls in providing good flow conditions within the basin proper. However, as mentioned previously in this report, the types 32 and 34 designs were about equally effective in protecting the bed of the exit channel from erosion. Attention is invited to the fact that bottom velocities over the riprapped side slopes of the exit channel were higher with a trapezoidal-shaped basin, since the side slopes of the exit channel were a continuation of the basin walls. On the other hand the use of vertical-type walls formed a slack-water area over the riprapped side slopes immediately below the basin.

TABLES

TABLE 1

PRESSURES OVER SPILLWAY CREST AND CHUTE

ORIGINAL DESIGN

Piezometer Number	Elevation of Piezometer	Discharge = 20,000 cfs Pool Elev. = 275.7 Tailwater Elev. = 215.0		Discharge = 40,000 cfs Pool Elev. = 279.81 Tailwater Elev. 218.6		Discharge = 63,000 cfs Pool Elev. = 283.4 Tailwater Elev. = 222.7	
		Piezometer Reading	Pressures	Piezometer Reading	Pressures	Piezometer Reading	Pressures
1	260.0	276.0	16.0	280.0	20.0	283.5	23.5
2	263.0	275.5	12.5	279.5	16.5	282.5	19.5
3	267.0	273.5	6.5	275.5	8.5	276.5	9.5
4	268.0	271.5	3.5	271.5	3.5	270.5	2.5
5	267.9	271.5	3.5	272.0	4.0	272.5	4.5
6	267.3	270.5	3.0	272.0	4.5	273.0	5.5
7	260.0	262.0	2.0	265.0	5.0	267.0	7.0
8	250.0	251.0	1.0	253.0	3.0	255.0	5.0
9	235.0	236.0	1.0	237.0	2.0	239.0	4.0
10	228.0	226.5	- 1.5	227.5	- 0.5	229.0	1.0
11	210.0	210.0	0.0	210.0	0.0	212.0	2.0
12	205.0	205.0	0.0	205.0	0.0	205.5	0.5
13	200.0	209.0	9.0	208.5	8.5	203.0	3.0

NOTE: Piezometer readings are recorded in ft msl.
Pressures are recorded in prototype ft of water to the nearest 0.5 ft.
Location of piezometers are shown on plate 7.

TABLE 2

STILLING-BASIN DESIGNS INVESTIGATED

Basin Design	Type Chute	Length of Apron (ft)	Width of Basin (ft)	Location of End Sill (ft)	Height of End Sill (ft)	Location of Baffles		Height of Baffles		Slope of Basin Walls	Reference	Remarks
						Row No. 1 (ft)	Row No. 2 (ft)	Row No. 1 (ft)	Row No. 2 (ft)			
Original	Flat	360	200	---	---	---	---	---	---	1 on 2		Basin as originally designed.
1	Flat	360	200	---	---	---	---	---	---	1 on 2		Ten-ft dentates located across toe of chute.
2	Flat	240	84	---	---	---	---	---	---	1 on 2	Figure 8	Transition from chute walls to basin walls.
3	Flat	150	84	145	5	30	45	5	10	1 on 2	Figure 8	Transition from chute walls to basin walls.
4	Flat	150	84	145	5	30	45	5	10	1 on 2	Figure 8	Ten-ft dentates located across toe of chute. Transition from chute walls to basin walls.
5	Flat	150	84	145	5	30	45	5	10	1 on 2	Figure 8	Ten-ft solid step located across toe of chute. Transition from chute walls to basin walls.
6	Flat	240	144	---	---	---	---	---	---	1 on 2	Figure 11	Ten-ft solid step located across toe of chute. Transition from chute walls to basin walls.
7	Flat	150	144	145	5	30	45	5	10	1 on 2	Figure 11	Ten-ft solid step located across toe of chute. Transition from chute walls to basin walls.
8	Flat	150	144	145	5	30	45	5	10	1 on 2	Figure 11	Ten-ft dentates located across toe of chute. Transition from chute walls to basin walls.
9	Flat	150	144	145	5	30	45	5	10	1 on 2	Figure 11	Ten-ft dentates removed from toe of chute. Transition from chute walls to basin walls.
10	Flat	240	144	---	---	---	---	---	---	1 on 2	Figure 11	Transition from chute walls to basin walls.
11	Flat	150	144	145	5	36	64	8	12	1 on 2	Figure 11	Five-ft solid step located across toe of chute. Transition from chute walls to basin walls.
12	Flat	150	200	145	5	36	64	8	12	1 on 2		1 on 4 chute slope from top of conduit ending in a solid step 10 ft high. Channel excavated on each side to deflect flow.
13	Arched	150	200	145	5	36	64	8	12	1 on 2		Chute arched transversely 6.7 ft higher in center, tapered to original elevation at sides. Transition from chute to basin.
14	Arched	150	200	145	5	36	64	8	12	1 on 2		Chute arched transversely 3.3 ft higher in center, tapered to original elevation at sides. Transition from chute to basin.
15	Arched	150	200	145	5	36	64	8	12	1 on 2		Chute arched transversely 3.3 ft higher in center, tapered to original elevation at sides. Five ft solid step, deflectors at toe of chute.
16	Flat	150	200	145	5	36	64	8	12	1 on 2		Original design chute with 10-ft deflectors near each chute wall at entrance to basin.
17	Flat	150	200	145	5	36	64	8	12	Vertical		Transition from chute walls to basin walls.
18	Flat	150	200	145	5	---	---	---	---	Vertical		Transition from chute walls to basin walls.
19	Flat	150	200	145	5	60	88	8	12	Vertical		Transition from chute walls to basin walls.

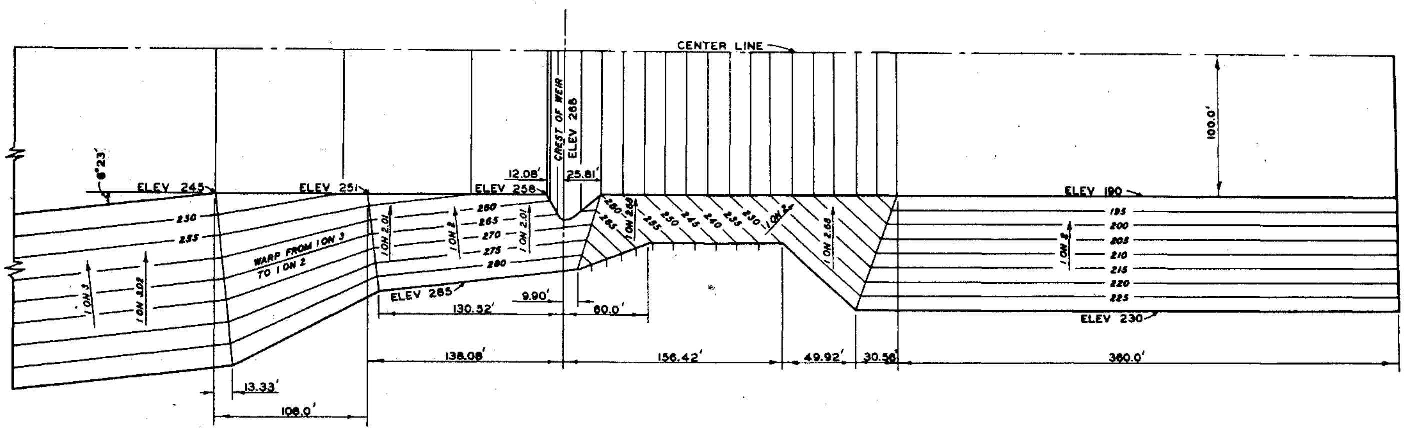
TABLE 2 (Continued)

STILLING-BASIN DESIGNS INVESTIGATED

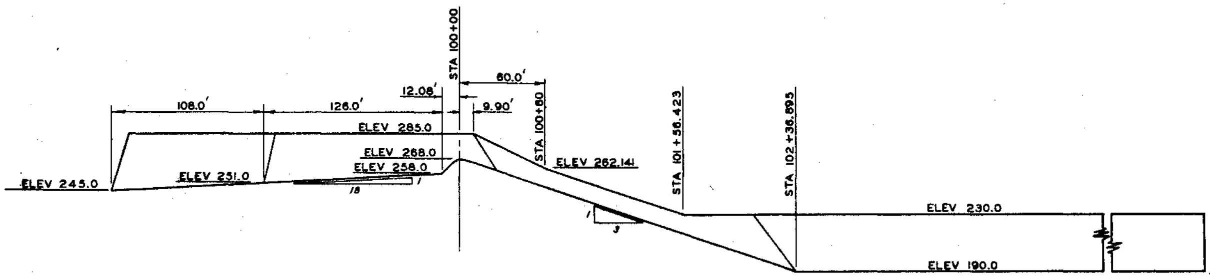
Basin Design	Type Chute	Length of Apron (ft)	Width of Basin (ft)	Location of End Sill (ft)	Height of End Sill (ft)	Location of Baffles Row No. 1 (ft)	Location of Baffles Row No. 2 (ft)	Height of Baffles Row No. 1 (ft)	Height of Baffles Row No. 2 (ft)	Slope of Basin Walls	Reference	Remarks
20	Flat	150	200	145	5	45	---	12	---	Vertical		Transition from chute walls to basin walls.
21	Flat	150	200	145	5	75	103	8	12	Vertical		Transition from chute walls to basin walls.
22	Flat	150	200	145	5	45	73	8	12	Vertical		Transition from chute walls to basin walls.
23	Flat	150	200	145	5	75	93	8	12	Vertical		Transition from chute walls to basin walls.
24	Flat	150	200	145	5	25	44	6	6	Vertical		Transition from chute walls to basin walls.
25	Flat	150	200	145	5	75	93	6	6	Vertical		Transition from chute walls to basin walls.
26	Flat	150	200	---	---	---	---	---	---	Vertical		Transition from chute walls to basin walls.
27	Flat	150	200	145	5	25	44	6	6	Vertical		Vertical walls extended from crest to end of apron.
28	Arched	265	160	260	5	70	90	6	6	1 on 2	Figure 17	Chute arched transversely 3.3 ft higher in center, tapered to original elevation at sides. Transition from chute walls to basin walls.
29	Arched	150	200	145	5	---	---	---	---	1 on 2		Chute arched transversely 5.12 ft higher in center, tapered to original elevation at sides. Transition from chute walls to basin walls.
30	Arched	100	200	95	5	---	---	---	---	1 on 2		Chute arched transversely 5.12 ft higher in center, tapered to original elevation at sides. Transition from chute walls to basin walls.
31	Arched	100	200	95	5	35	---	8	---	1 on 2		Chute arched transversely 5.12 ft higher in center, tapered to original elevation at sides. Transition from chute walls to basin walls.
32	Arched	100	200	95	5	35	56	8	8	1 on 2	Figure 18	Chute arched transversely 5.12 ft higher in center, tapered to original elevation at sides. Transition from chute walls to basin walls.
33	Arched	100	200	95	5	35	56	6	6	1 on 2		Chute arched transversely 5.12 ft higher in center, tapered to original elevation at sides. Transition from chute walls to basin walls.
34	Flat	100	200	95	5	35	56	8	8	1 on 2	Figure 19	Two 15-ft deflectors located on chute near each side-wall. Transition from chute walls to basin walls.
35	Flat	100	200	95	5	35	56	8	8	1 on 2	Figure 21	Same as type 34 design with deflector removed. Transition from chute walls to basin walls.
36	Flat	100	200	95	5	35	56	8	8	Vertical		Transition from chute walls to basin walls.
37	Flat	100	200	95	5	35	56	8	8	Vertical		Transition from chute walls to basin walls. Training walls extended and rounded on 100-ft radius.
38	Flat	100	200	95	5	35	56	8	8	1 on 2		Five-ft end sill extended up the 1-on-2 slopes of the stilling-basin walls.

NOTE: In all stilling-basin designs except the original, type 1, and type 27 warped transitions from the chute walls to the basin walls are used.

PLATES



HALF PLAN



PROFILE

SCALE

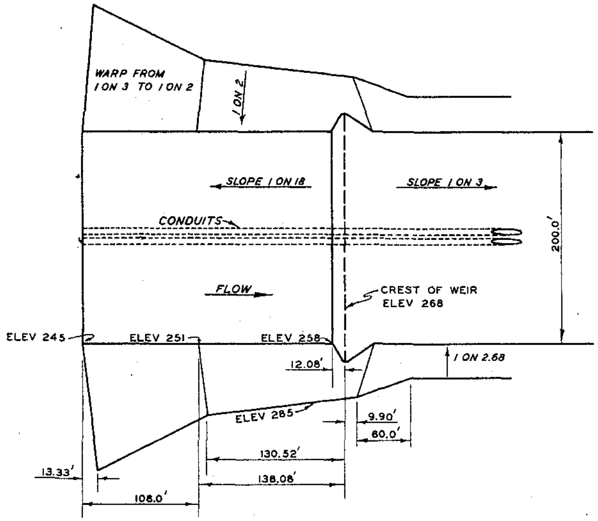
40 0 40 80 120 160 200 FT.

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

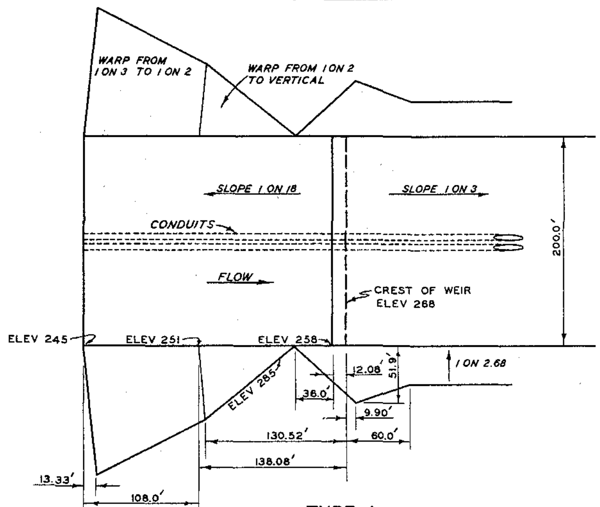
SPILLWAY PLAN AND PROFILE

ORIGINAL DESIGN

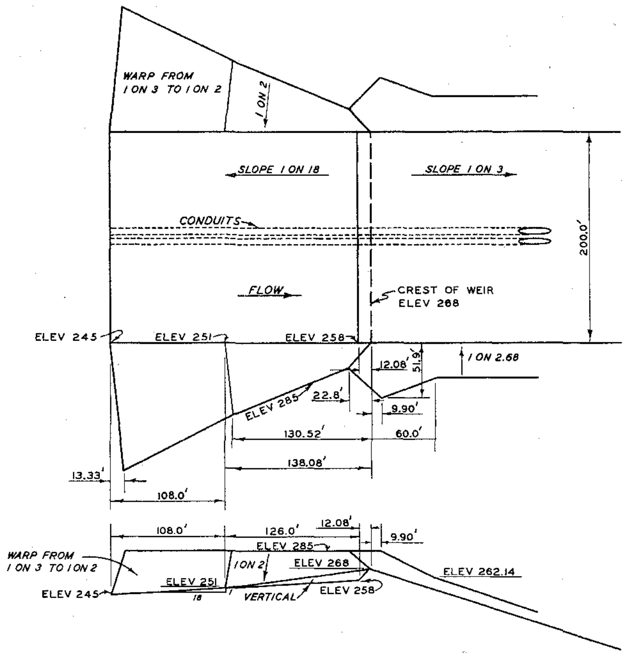
PLATE 1



ORIGINAL



TYPE A



TYPE B

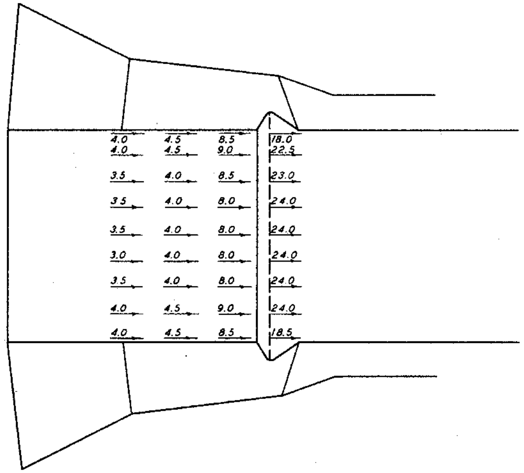
NOTE: SEE RATING CURVES
ON PLATE 6
DETAILS OF APPROACH CHANNELS
ARE ALSO SHOWN ON
PHOTOGRAPHS 3,6 AND 9

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

DETAILS OF APPROACH CHANNELS

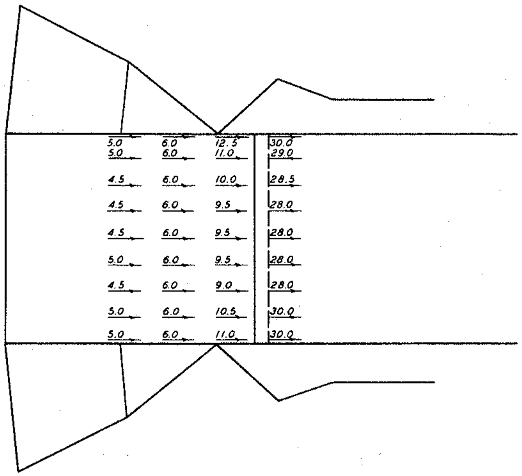
SCALE

60 0 60 120 FT



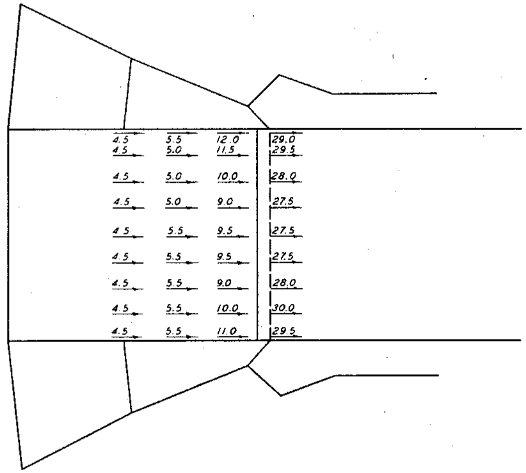
ORIGINAL

DISCHARGE = 63,000 CFS



TYPE A

DISCHARGE = 50,000 CFS



TYPE B

DISCHARGE = 50,000 CFS

NOTE: VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

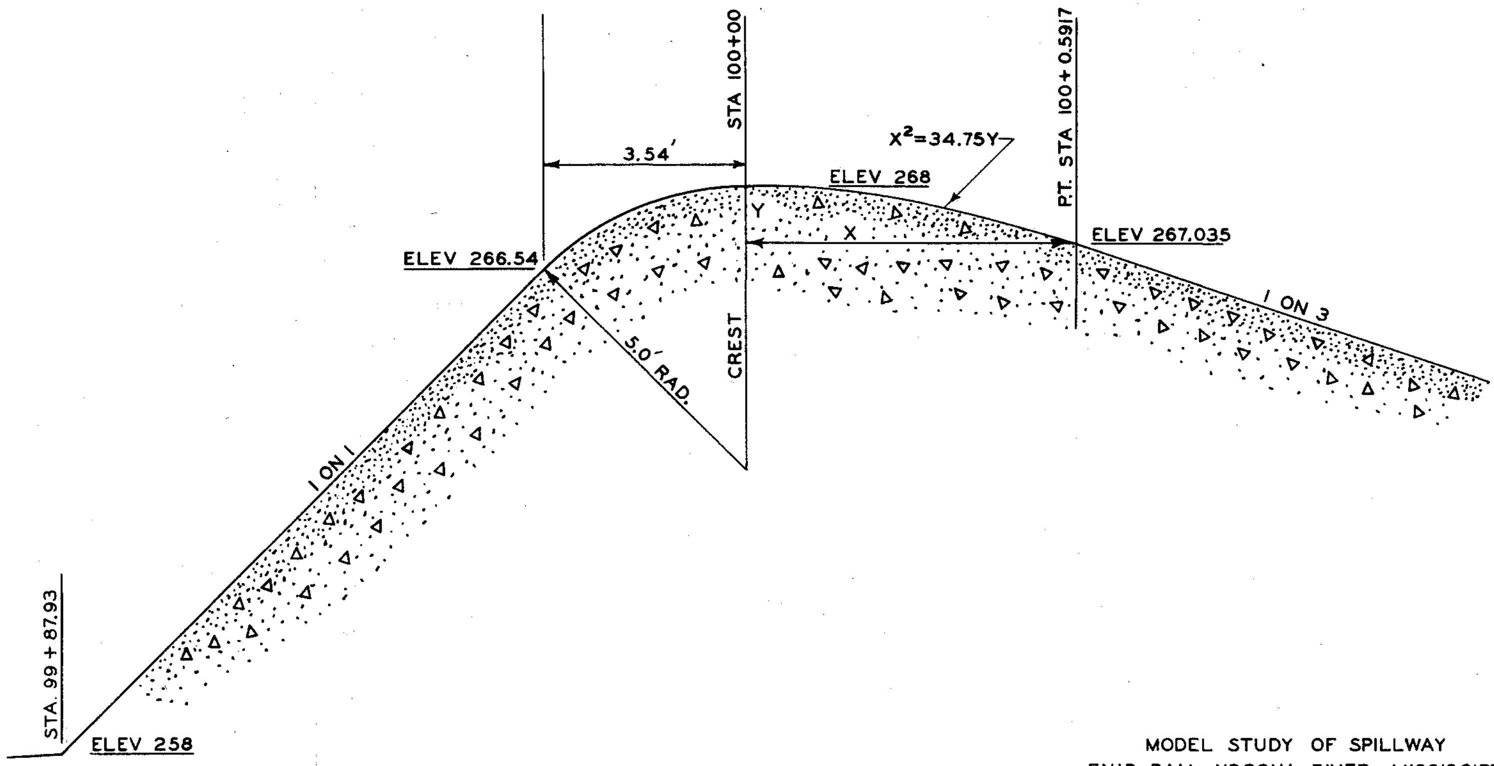
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES
ORIGINAL AND TYPES A AND B
APPROACH CHANNELS

SCALES

60 0 60 120 180 FT

PLATE 4

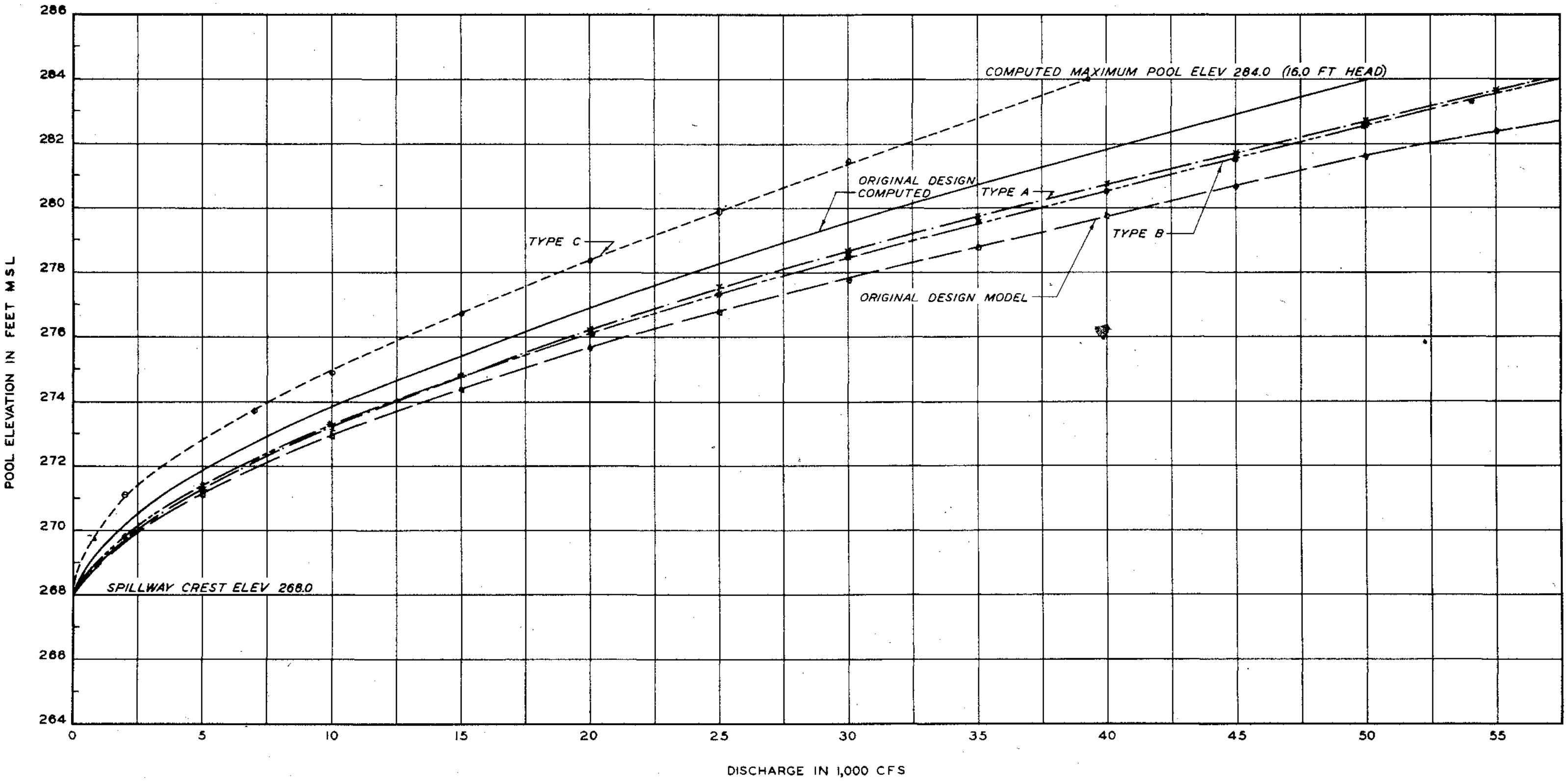


MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

DETAILS OF CREST SECTION
ORIGINAL DESIGN

SCALE

60 0 60 120 FT.



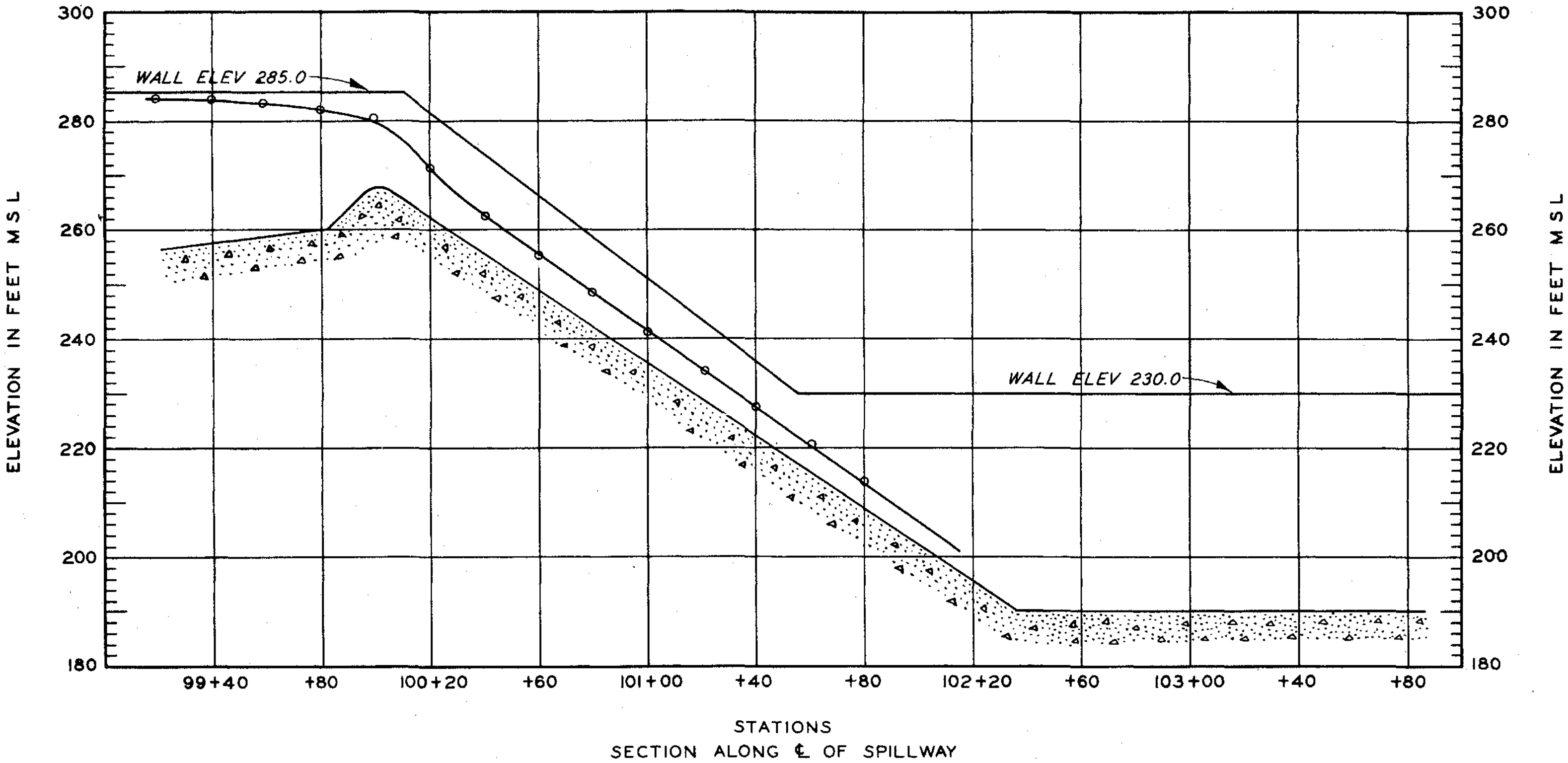
NOTE: VARIATION IN CREST LENGTH
ORIGINAL DESIGN - 237 FT
TYPE A - 200 FT
TYPE B - 200 FT
TYPE C - 160 FT (CURVED)

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SPILLWAY RATING CURVES

ORIGINAL AND TYPES A, B, AND C
APPROACH CHANNELS

PLATE 6

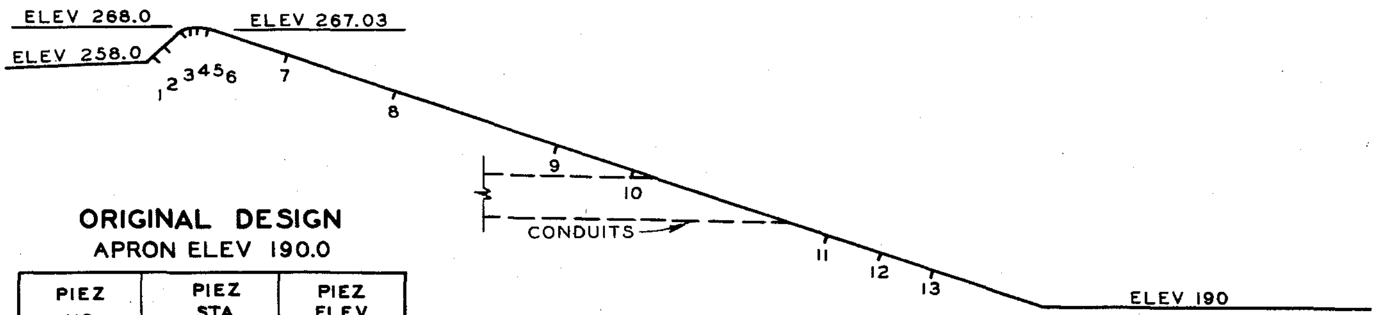


TEST DATA

DISCHARGE 63,000 CFS

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

WATER-SURFACE PROFILE
ORIGINAL DESIGN



ORIGINAL DESIGN
APRON ELEV 190.0

PIEZ NO.	PIEZ STA (FT)	PIEZ ELEV (FT MSL)
P-1	99+89.92	260.0
P-2	99+92.92	263.0
P-3	99+97.03	267.0
P-4	100+00.00	268.0
P-5	100+01.86	267.9
P-6	100+04.93	267.3
P-7	100+26.89	260.0
P-8	100+56.89	250.0
P-9	101+01.89	235.0
P-10	101+22.89	228.0
P-11	101+76.89	210.0
P-12	101+91.89	205.0
P-13	102+06.89	200.0

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

PIEZOMETER LOCATIONS

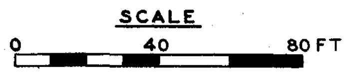
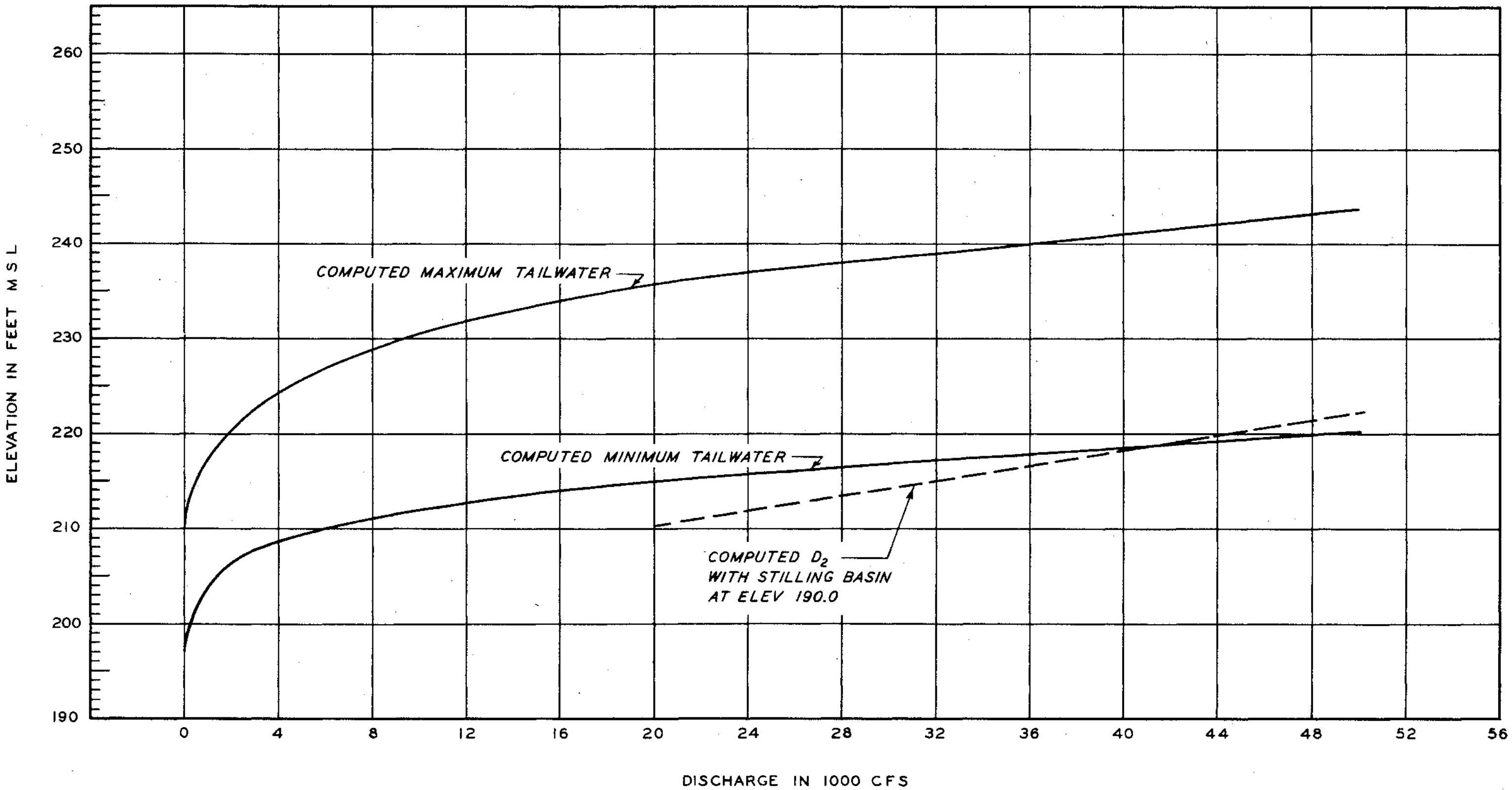


PLATE 8

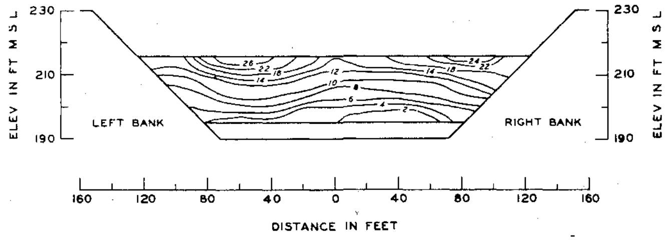


NOTES: MAXIMUM TAILWATER WAS COMPUTED ASSUMING NO SCOUR
MINIMUM TAILWATER WAS COMPUTED ASSUMING MAXIMUM SCOUR

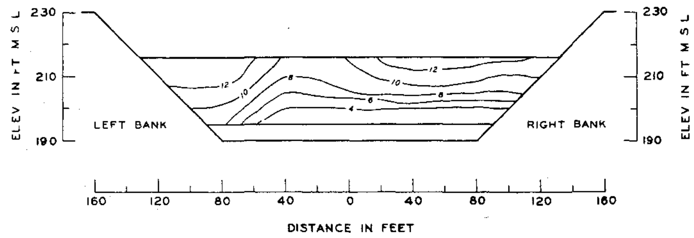
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

TAILWATER RATING CURVES

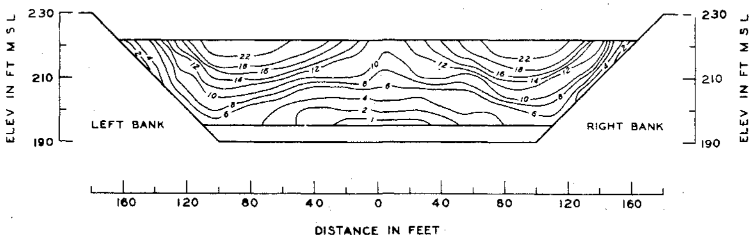
TYPE 11 DESIGN
STATION 103+86.89 (END SILL)
DISCHARGE = 53,800 CFS



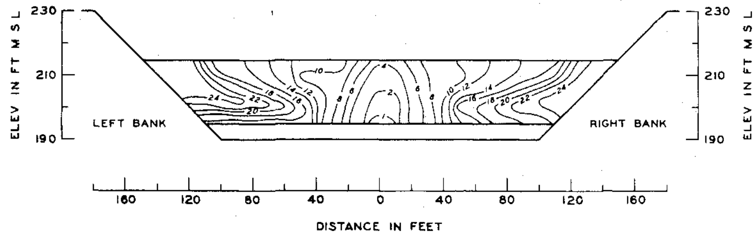
TYPE 28 DESIGN
STATION 105+01.89 (END SILL)
DISCHARGE = 40,600 CFS



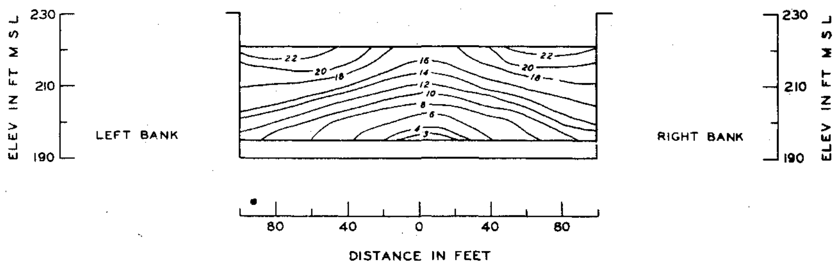
TYPE 14 DESIGN
STATION 103+86.89 (END SILL)
DISCHARGE = 53,800 CFS



TYPE 29 DESIGN
STATION 103+86.89 (END SILL)
DISCHARGE = 50,000 CFS



TYPE 25 DESIGN
STATION 103+86.89 (END SILL)
DISCHARGE = 53,800 CFS

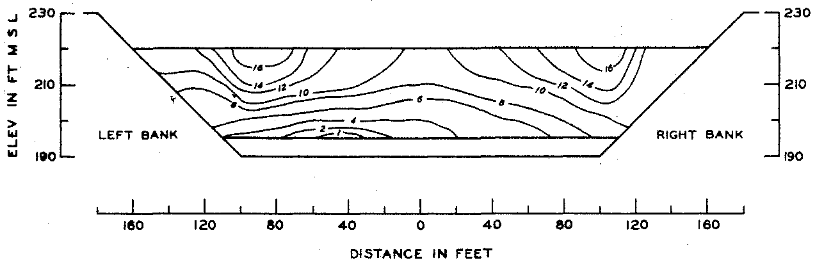


NOTE: VELOCITIES ARE IN PROTOTYPE
FT PER SEC

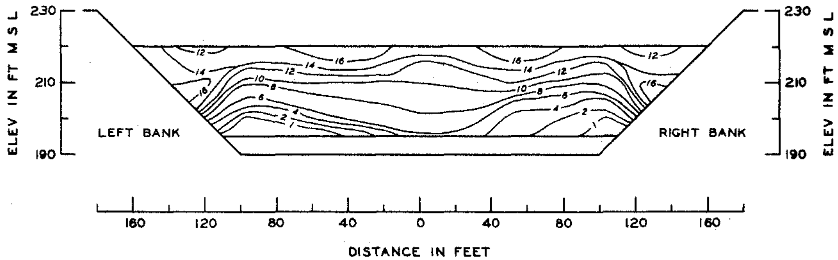
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

VELOCITY DISTRIBUTION AT END SILL

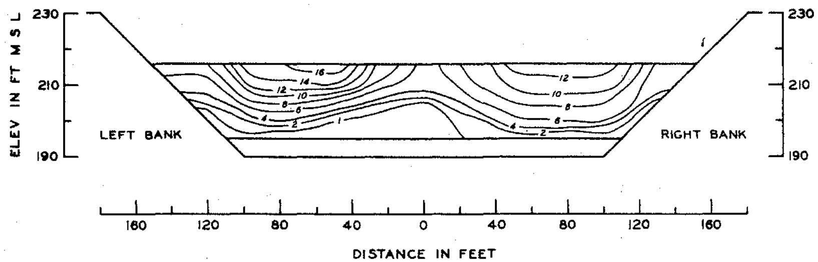
TYPE 32 DESIGN
STATION 103+36.89 (END SILL)
DISCHARGE = 50,000 CFS



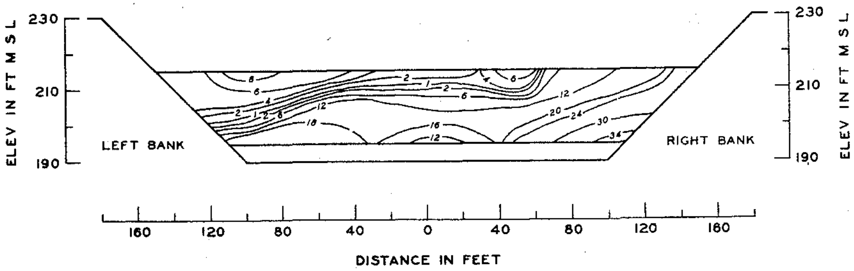
TYPE 34 DESIGN
STATION 103+36.89 (END SILL)
DISCHARGE = 50,000 CFS



TYPE 32 DESIGN
STATION 103+36.89 (END SILL)
DISCHARGE = 25,000 CFS



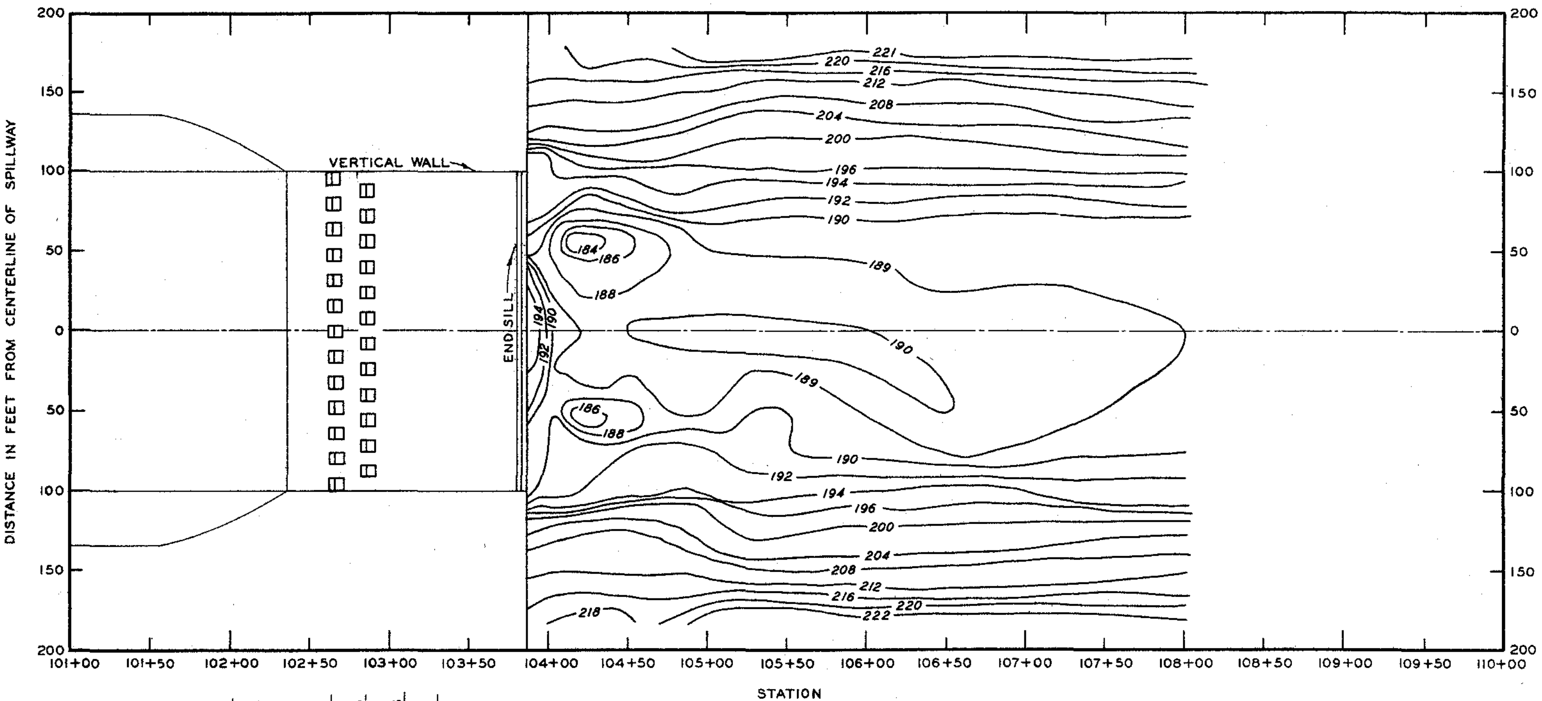
TYPE 30 DESIGN
STATION 103+36.89 (END SILL)
DISCHARGE = 50,000 CFS

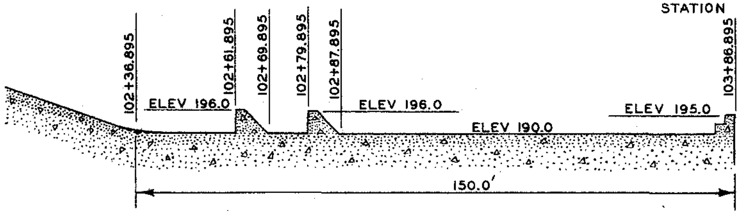


NOTE: VELOCITIES ARE IN PROTOTYPE FT PER SEC

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

VELOCITY DISTRIBUTION AT END SILL





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

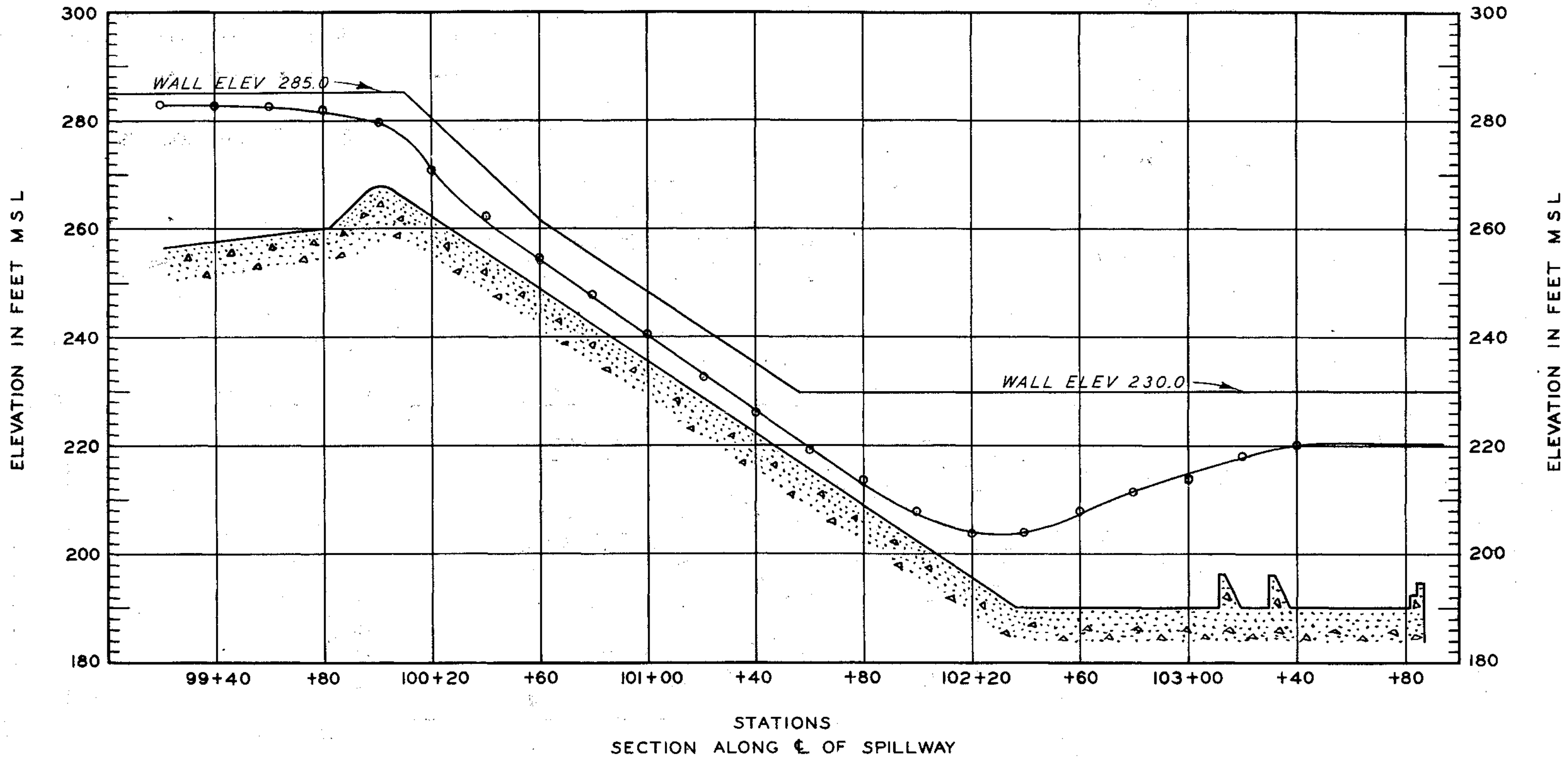
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 24 DESIGN

DISCHARGE 53,800 C F S
TAILWATER ELEVATION 221.7

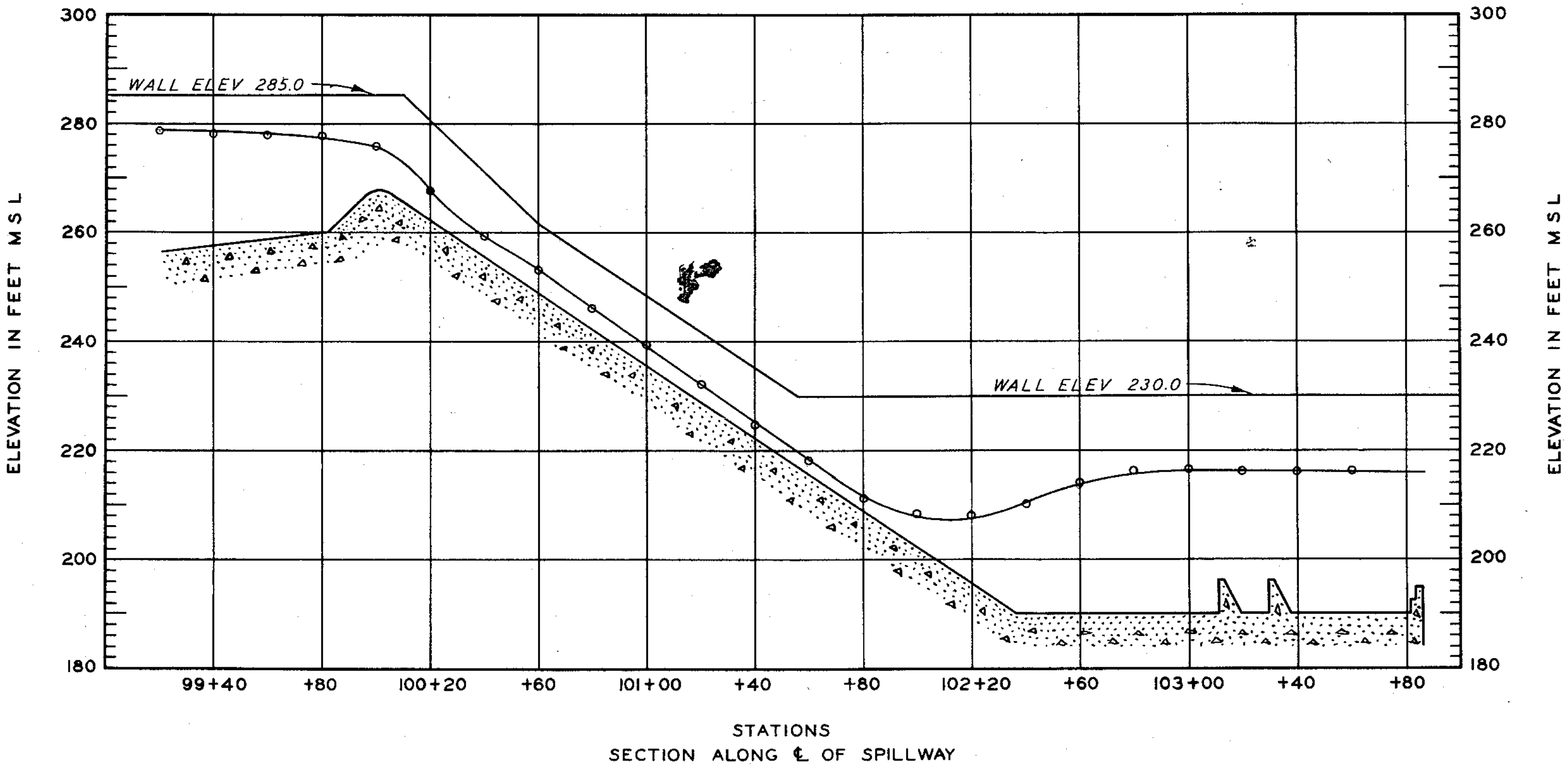


TEST DATA

DISCHARGE 50,000 C F S
TAILWATER ELEV 220.4

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

WATER-SURFACE PROFILE
TYPE 25 DESIGN



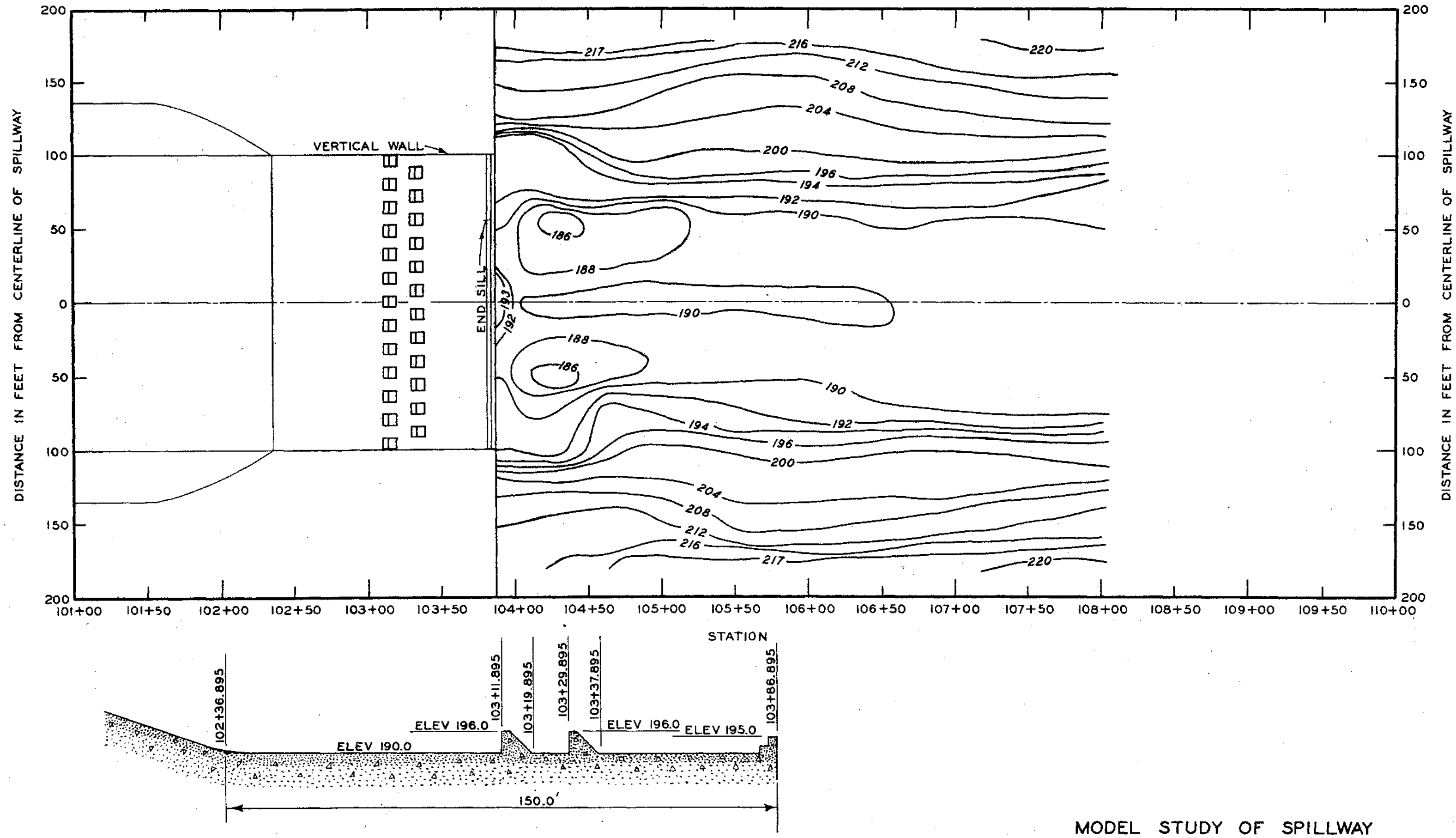
TEST DATA

DISCHARGE	25,000	C F S
TAILWATER ELEV	216.0	

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

WATER–SURFACE PROFILE
TYPE 25 DESIGN

PLATE 13



SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE
20 0 20 40 60 FEET

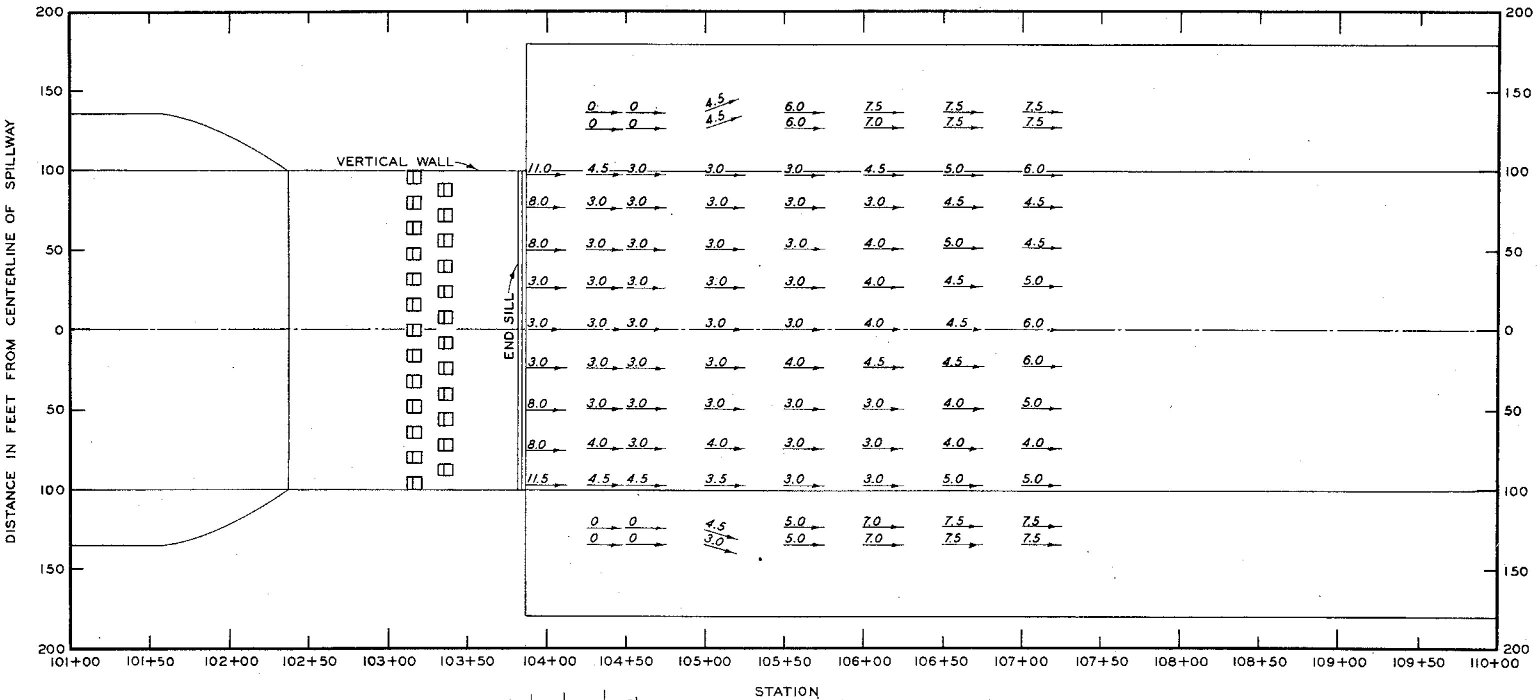
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

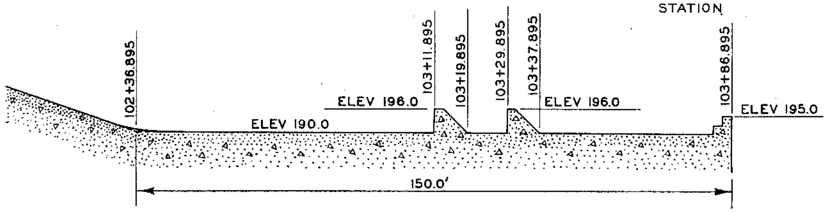
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 25 DESIGN

DISCHARGE 53,800 C F S
TAILWATER ELEVATION 221.7





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

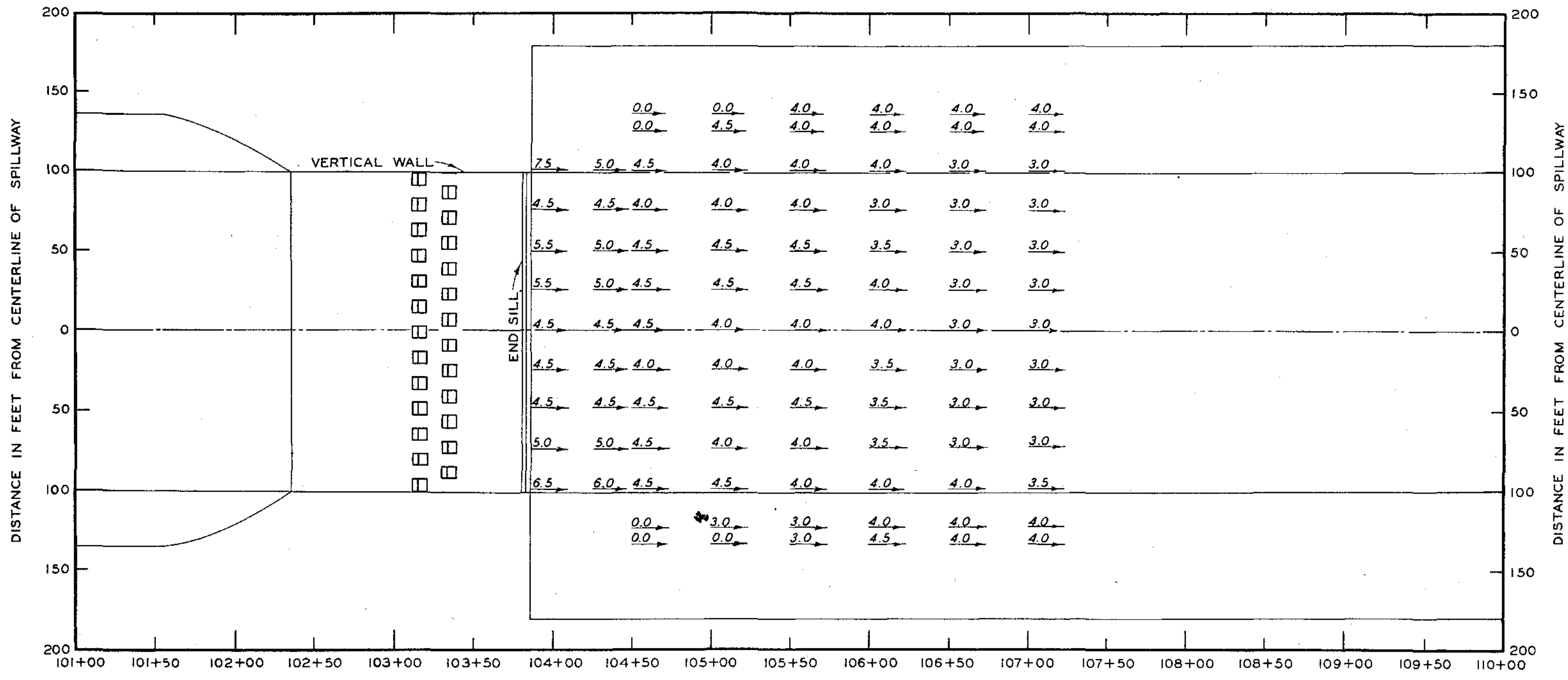
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION
VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

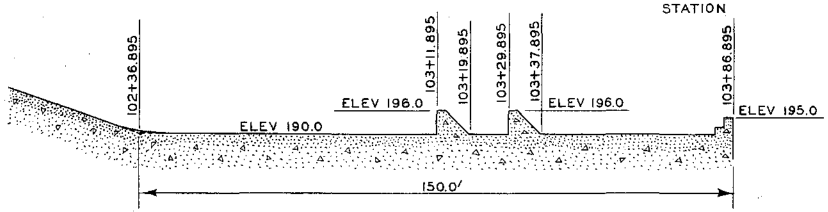
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES

TYPE 25 DESIGN

DISCHARGE 53,800 C F S
TAILWATER ELEVATION 221.7





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE
20 0 20 40 60 FEET

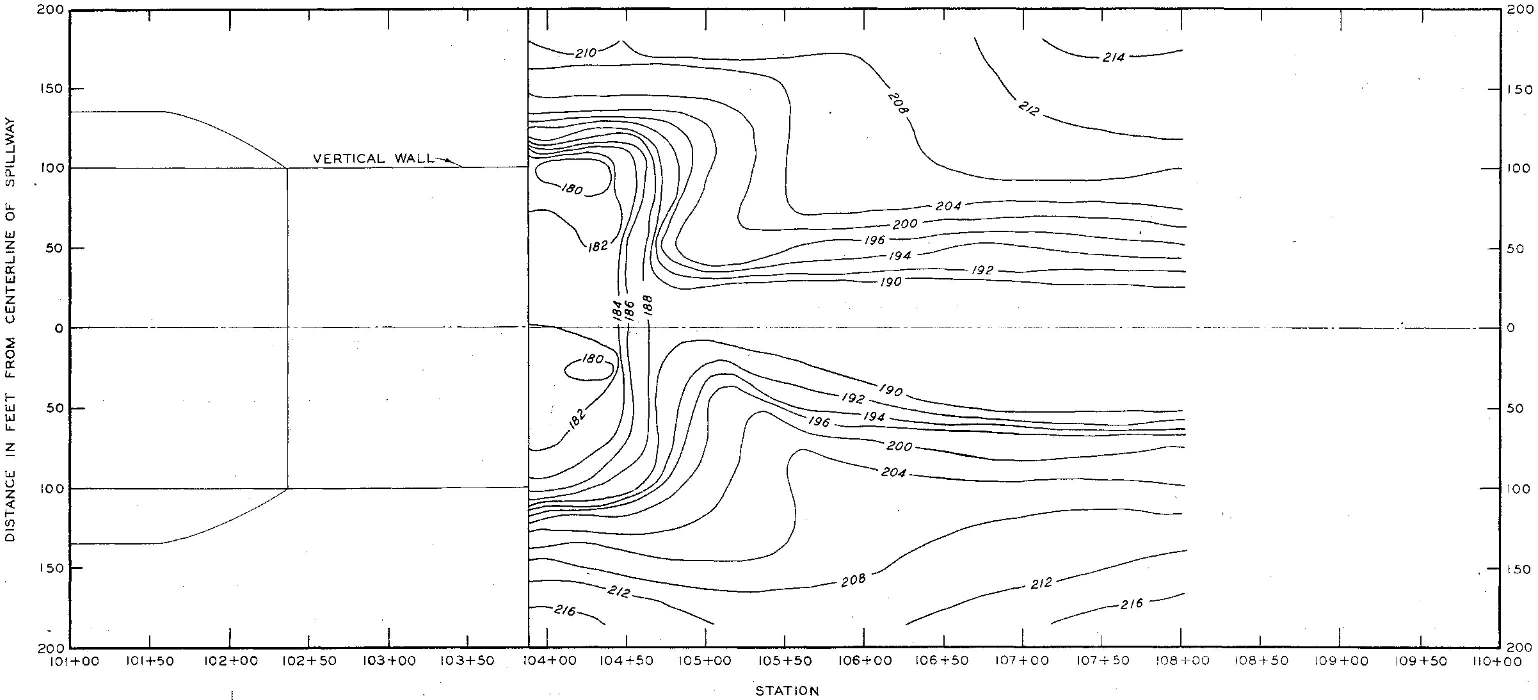
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION
VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

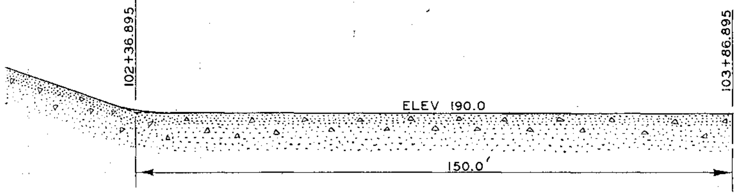
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES

TYPE 25 DESIGN

DISCHARGE 25,000 C F S
TAILWATER ELEVATION 216.0





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

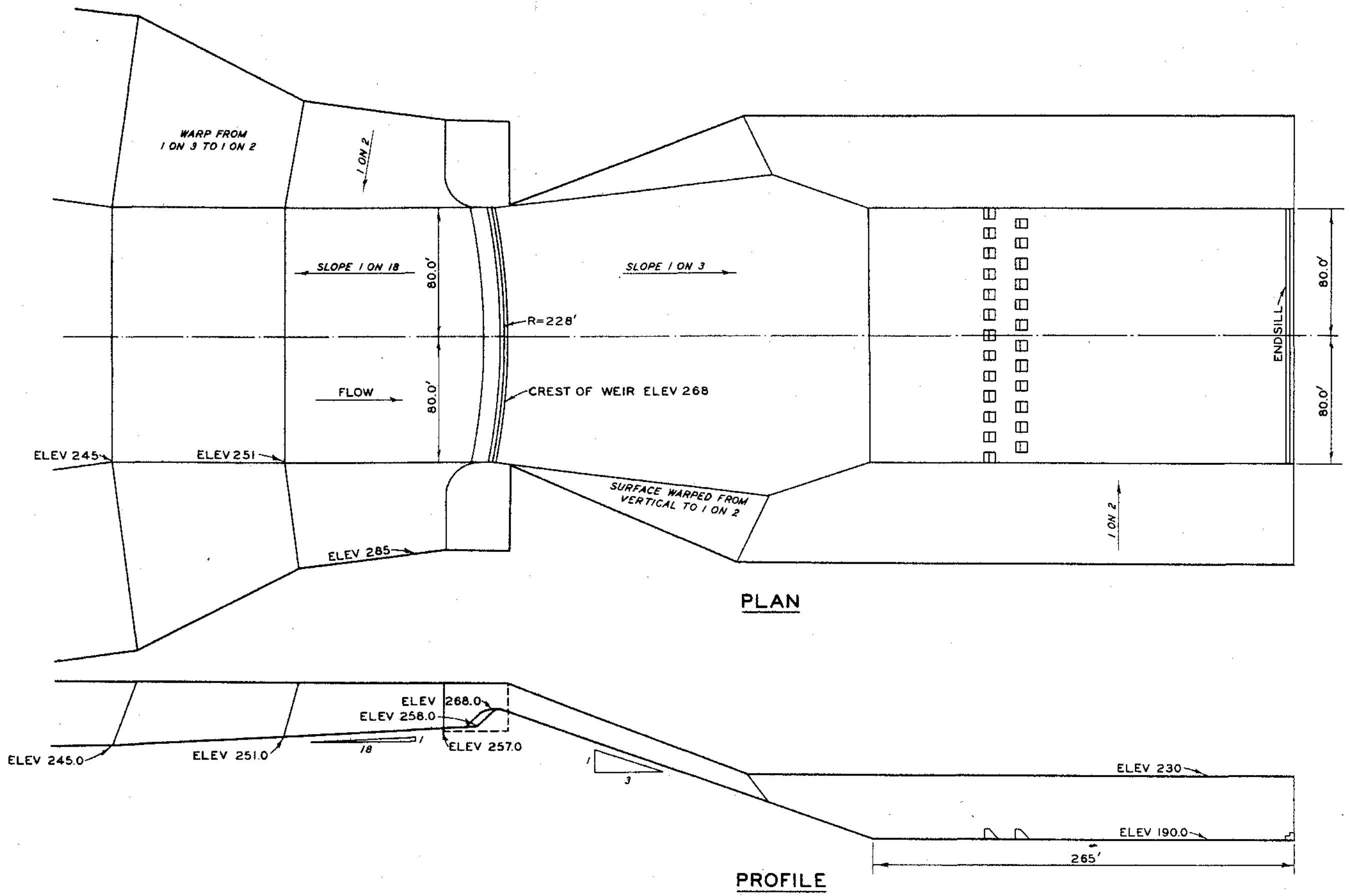
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

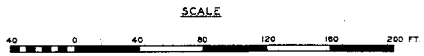
SCOUR PATTERN

TYPE 26 DESIGN

DISCHARGE 53,800 C F S
TAILWATER ELEVATION 221.7

PLATE 18

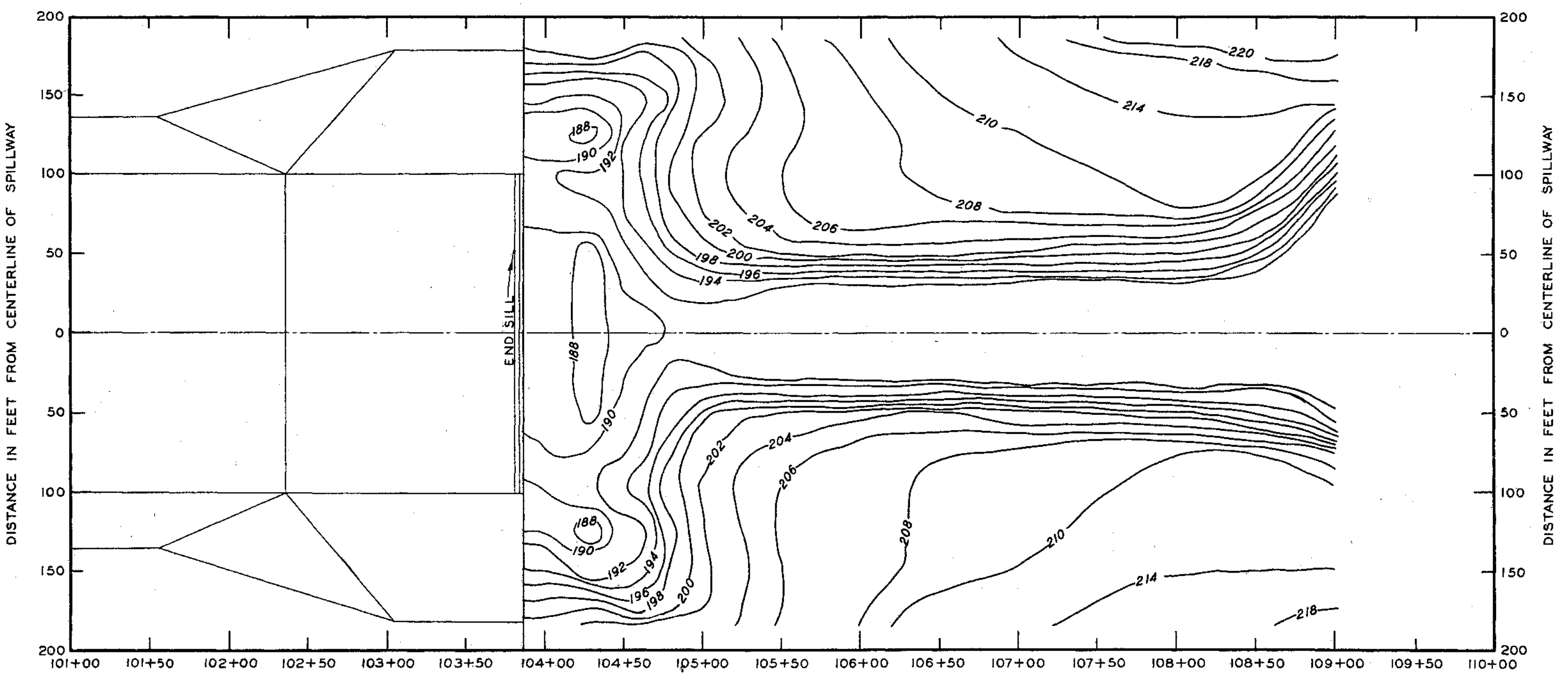


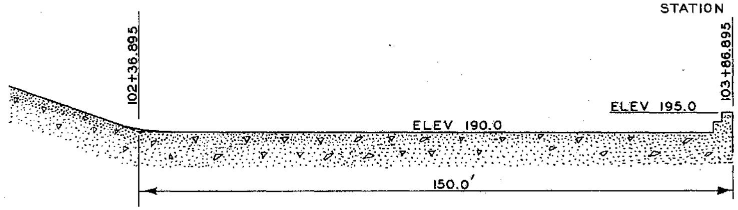


MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SPILLWAY PLAN AND PROFILE

TYPE 28 DESIGN





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

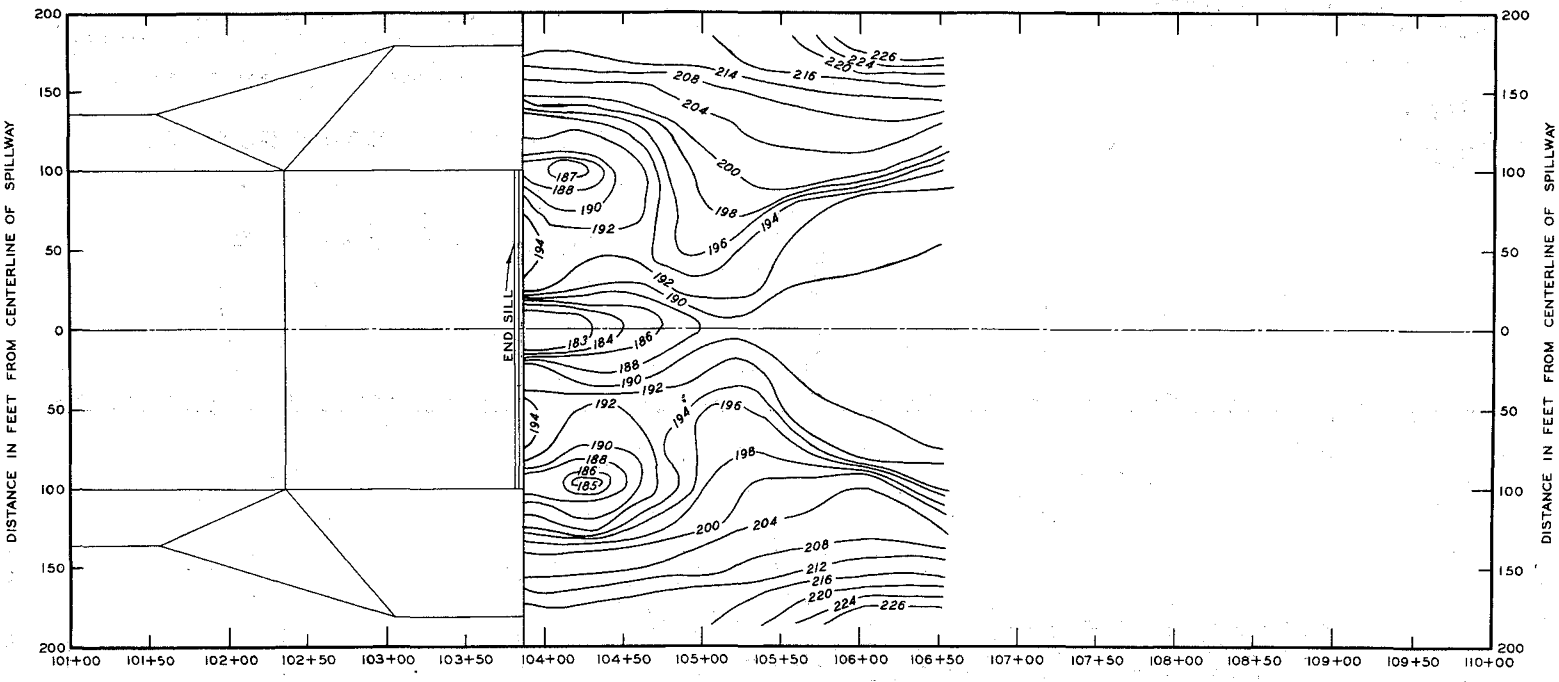
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

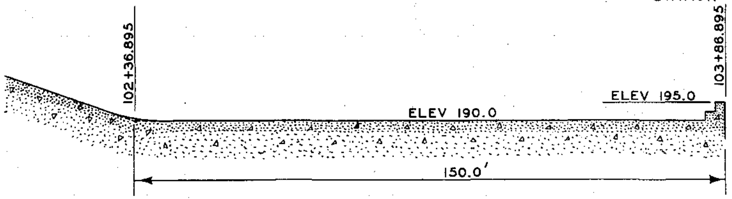
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 29 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

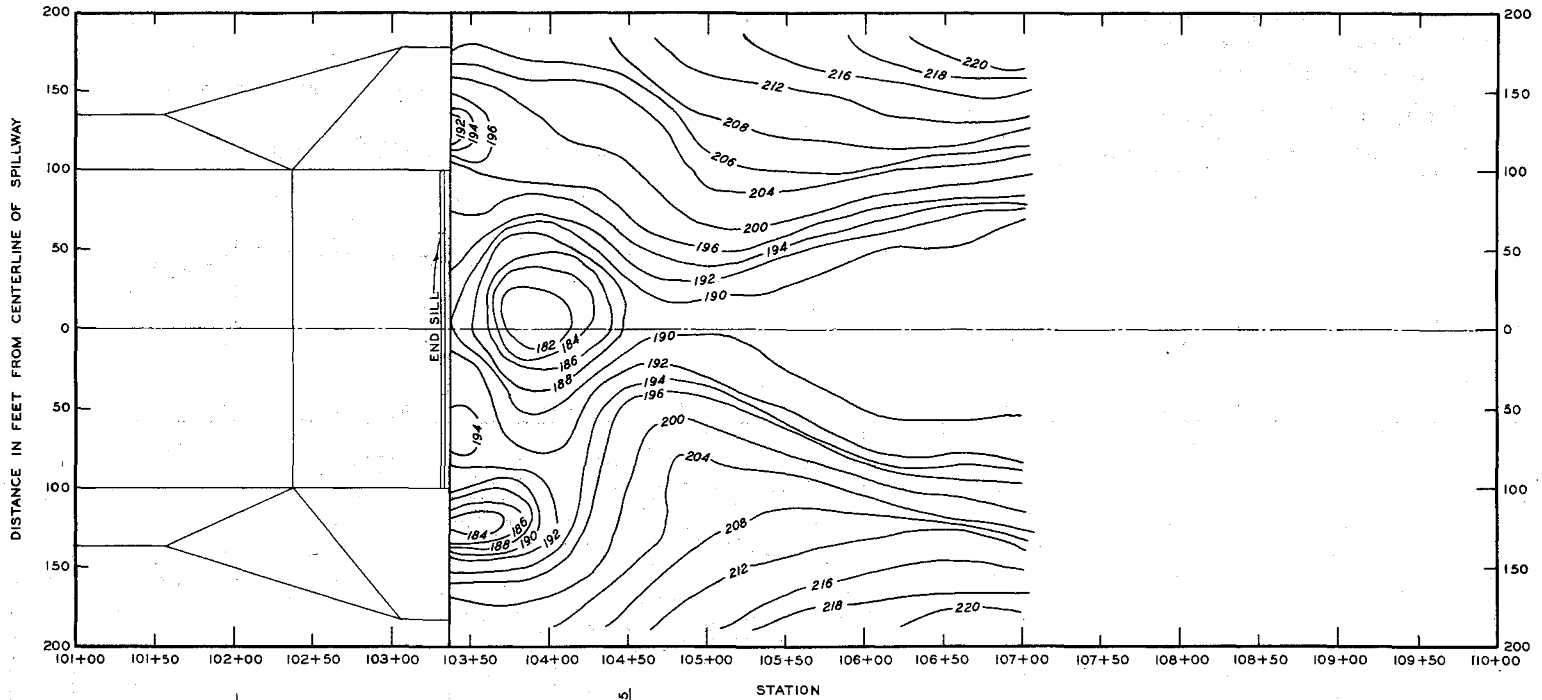
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

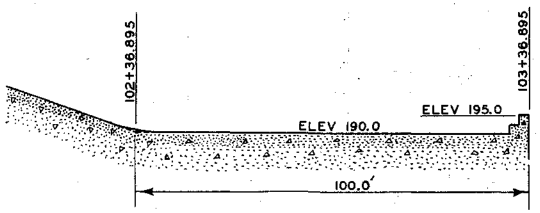
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 29 DESIGN

DISCHARGE 25,000 C F S
TAILWATER ELEVATION 216.0





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

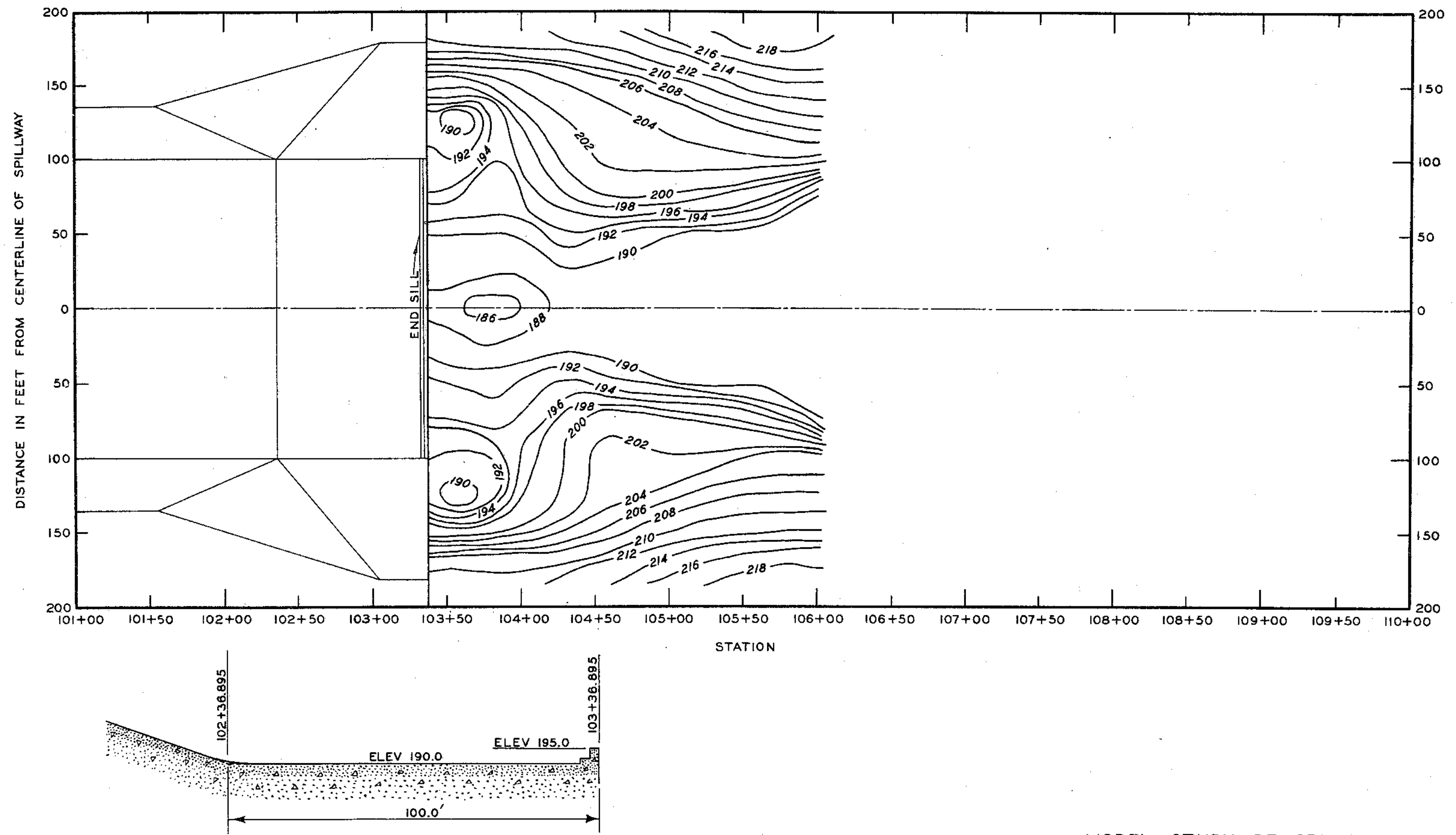
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M.S.L.
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 30 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4



SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE
20 0 20 40 60 FEET

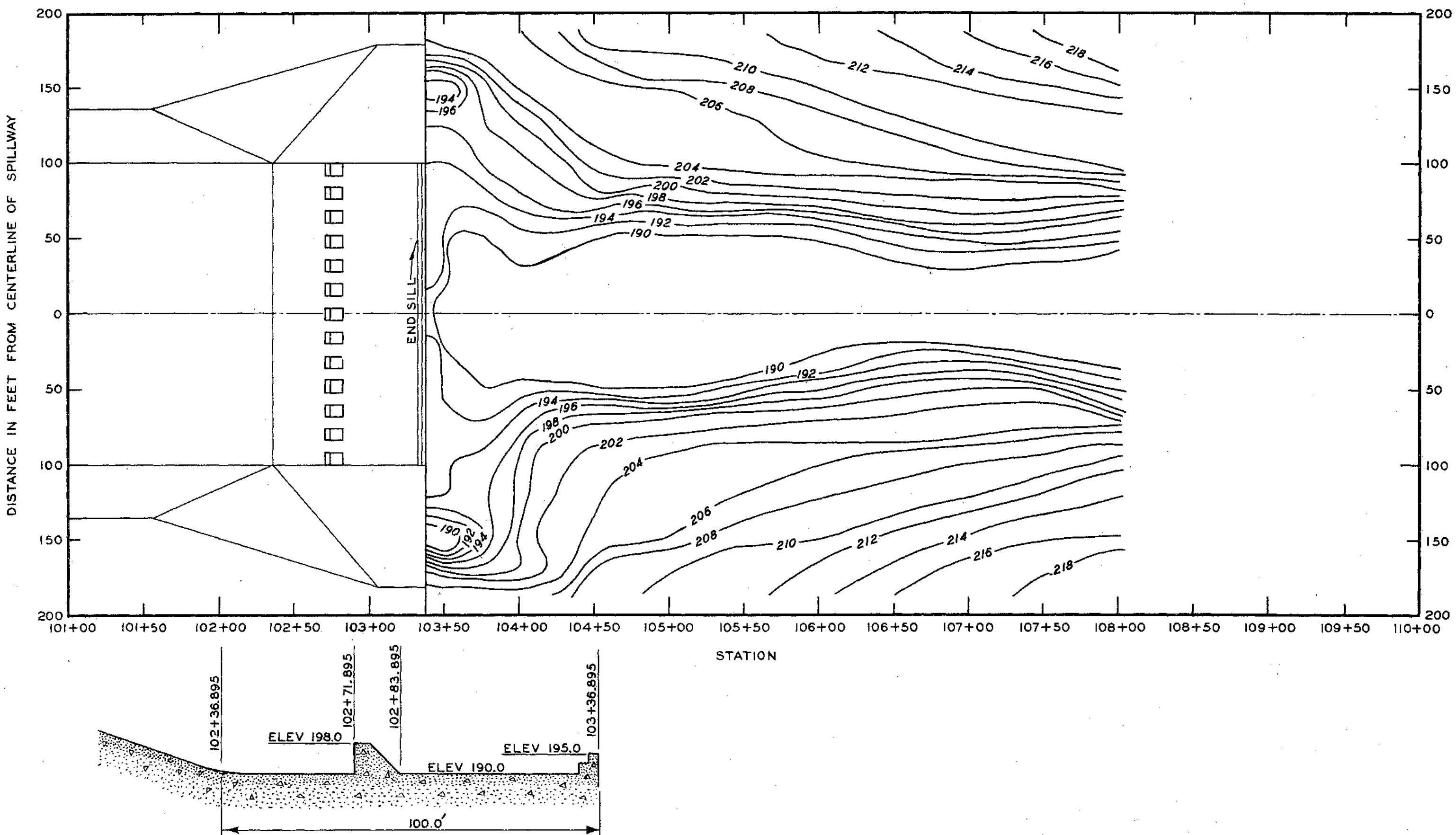
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 30 DESIGN

DISCHARGE 25,000 C F S
TAILWATER ELEVATION 216.0



SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

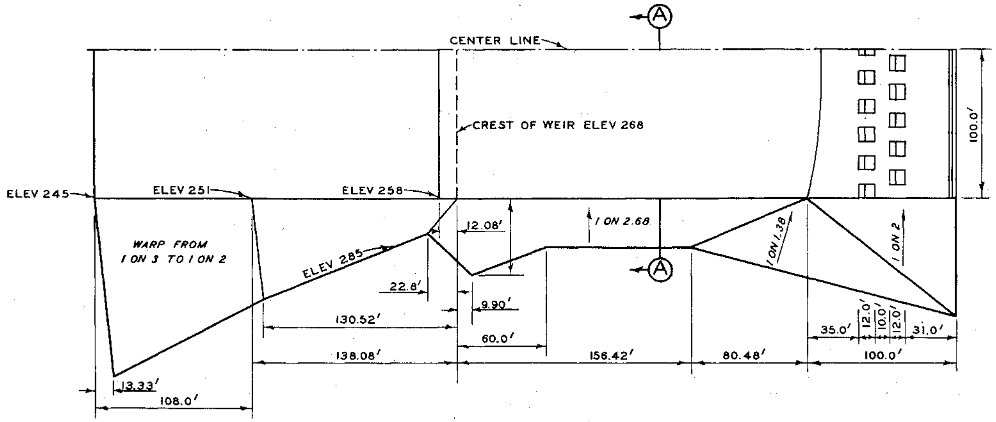
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

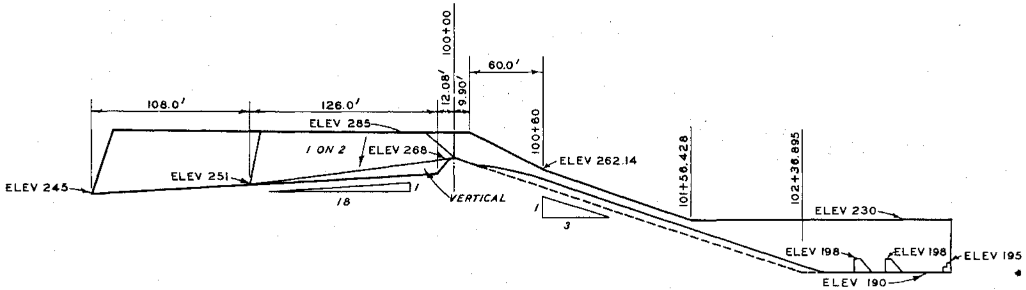
TYPE 31 DESIGN

DISCHARGE 50,000 C F S

TAILWATER ELEVATION 220.4



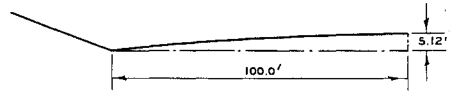
HALF PLAN



PROFILE

SCALE

60 0 60 120 180 FT



SECTION A-A

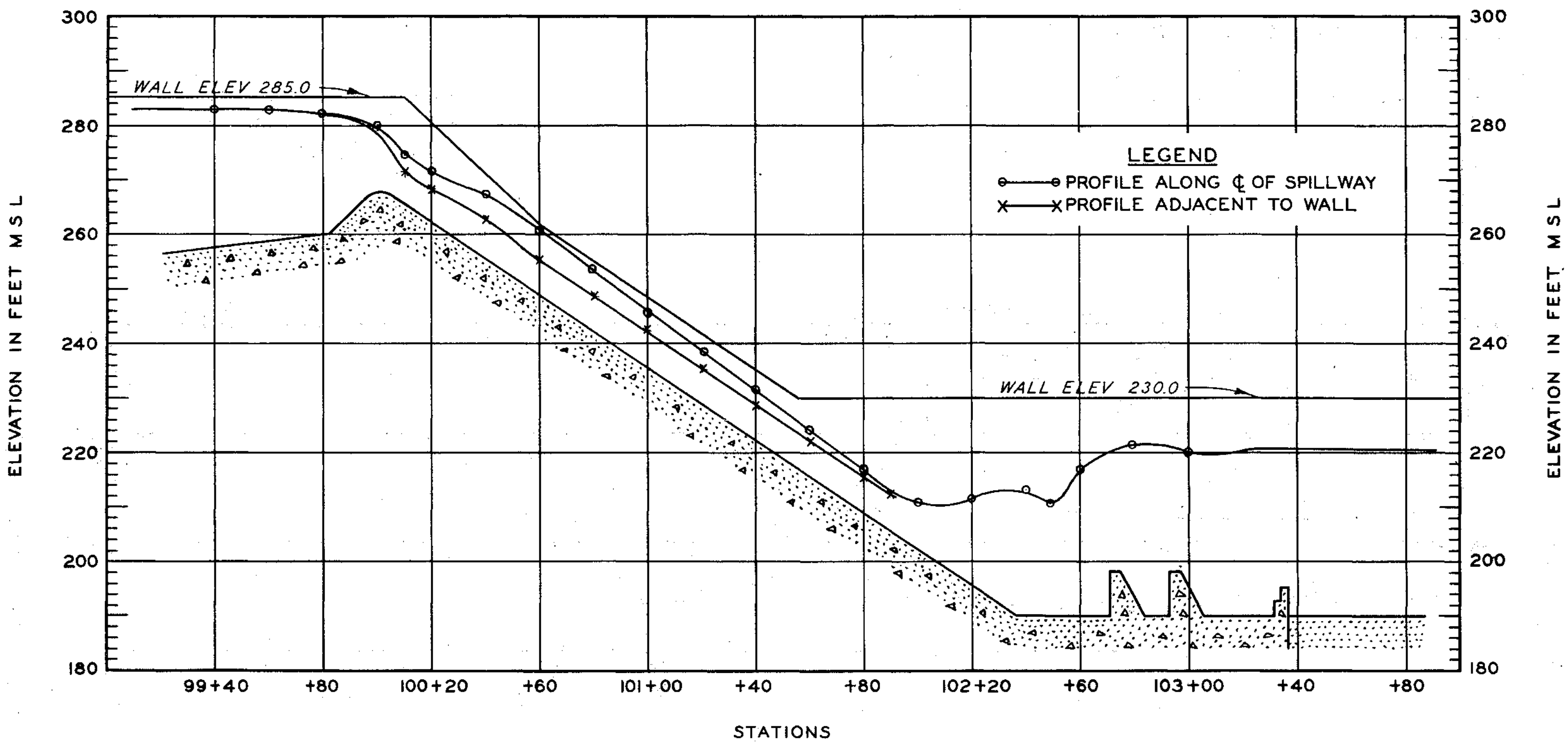
SCALE

30 0 30 FT

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SPILLWAY PLAN AND PROFILE

TYPE 32 DESIGN



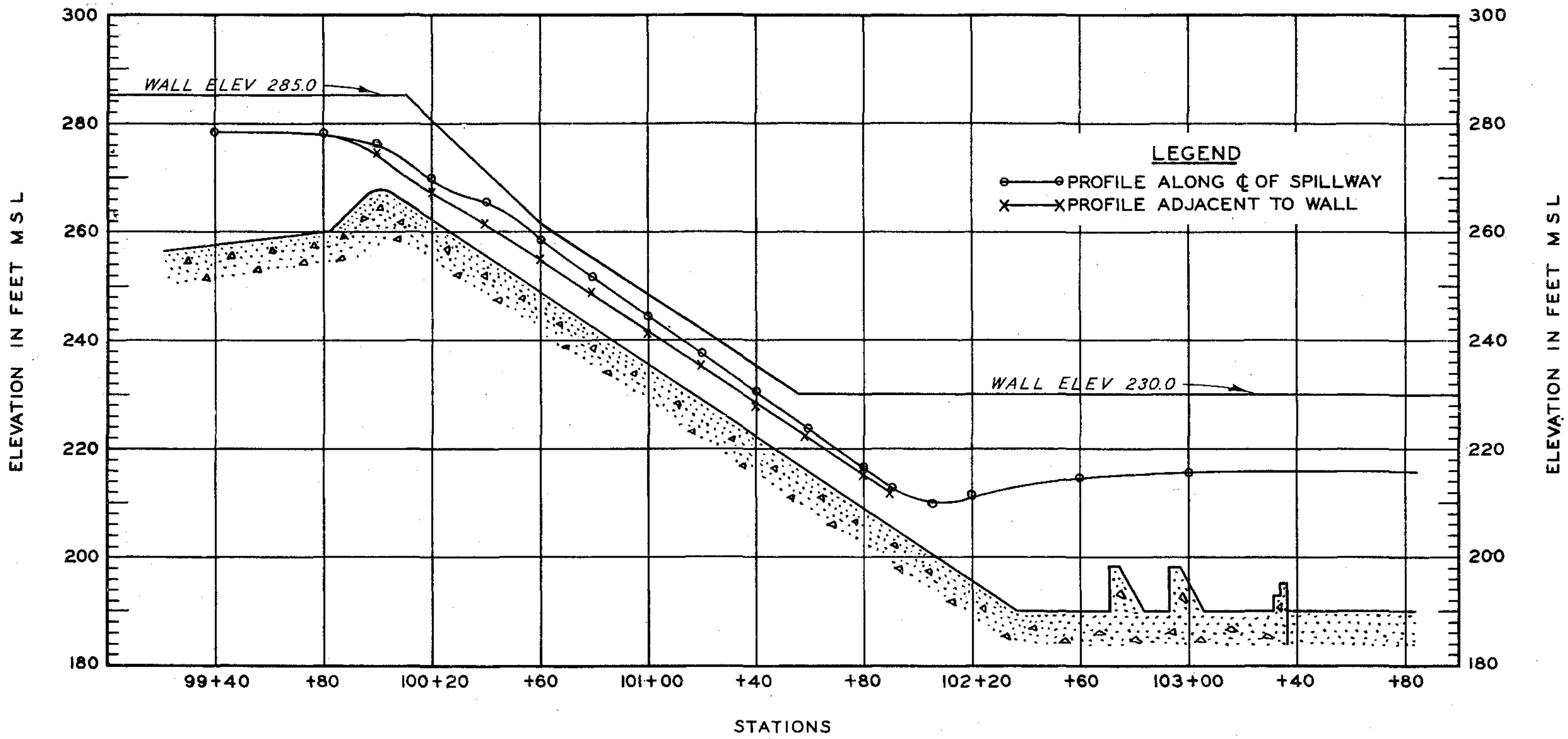
TEST DATA

DISCHARGE 50,000 C F S
TAILWATER ELEV 220.4

25 APR 194[illegible]

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

WATER-SURFACE PROFILE
TYPE 32 DESIGN

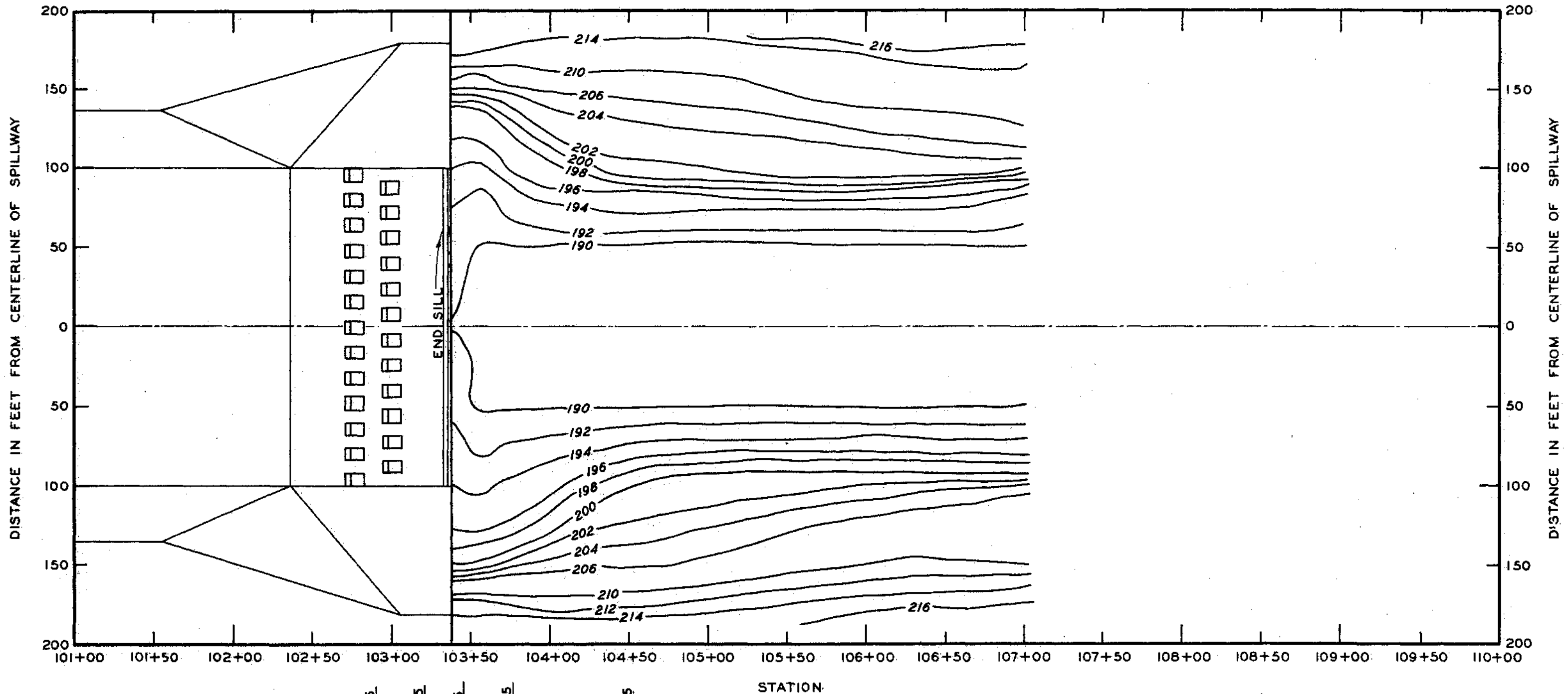


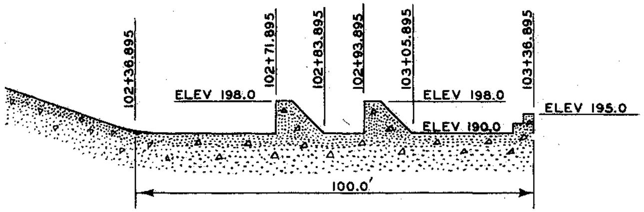
TEST DATA

DISCHARGE 25,000 C F S
TAILWATER ELEV 216.0

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

WATER-SURFACE PROFILE
TYPE 32 DESIGN





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

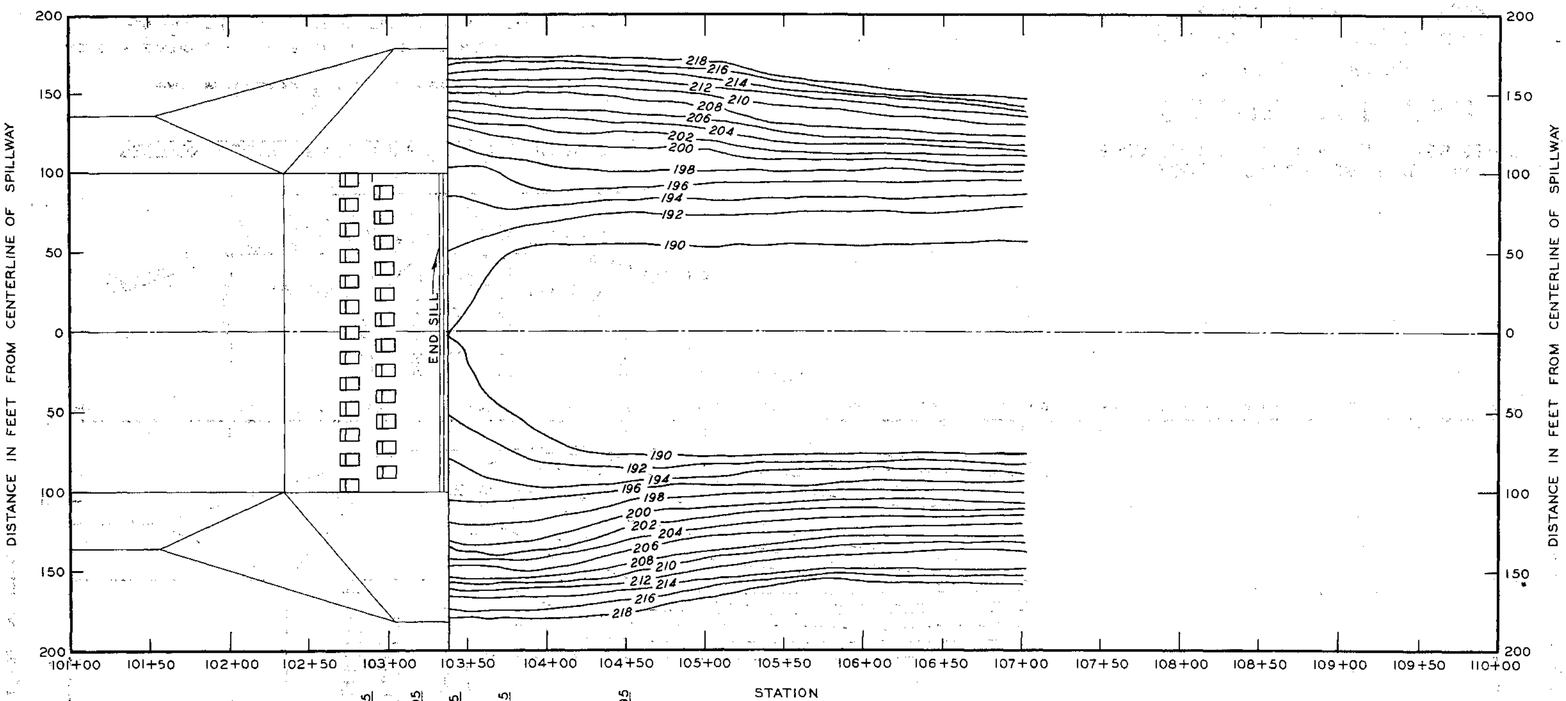
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

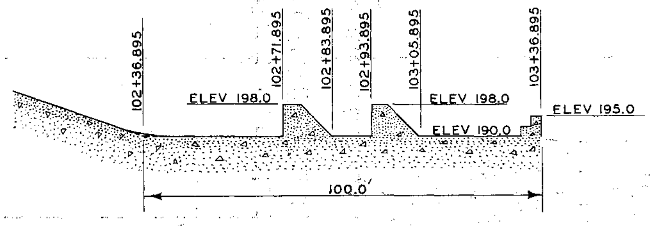
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 32 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

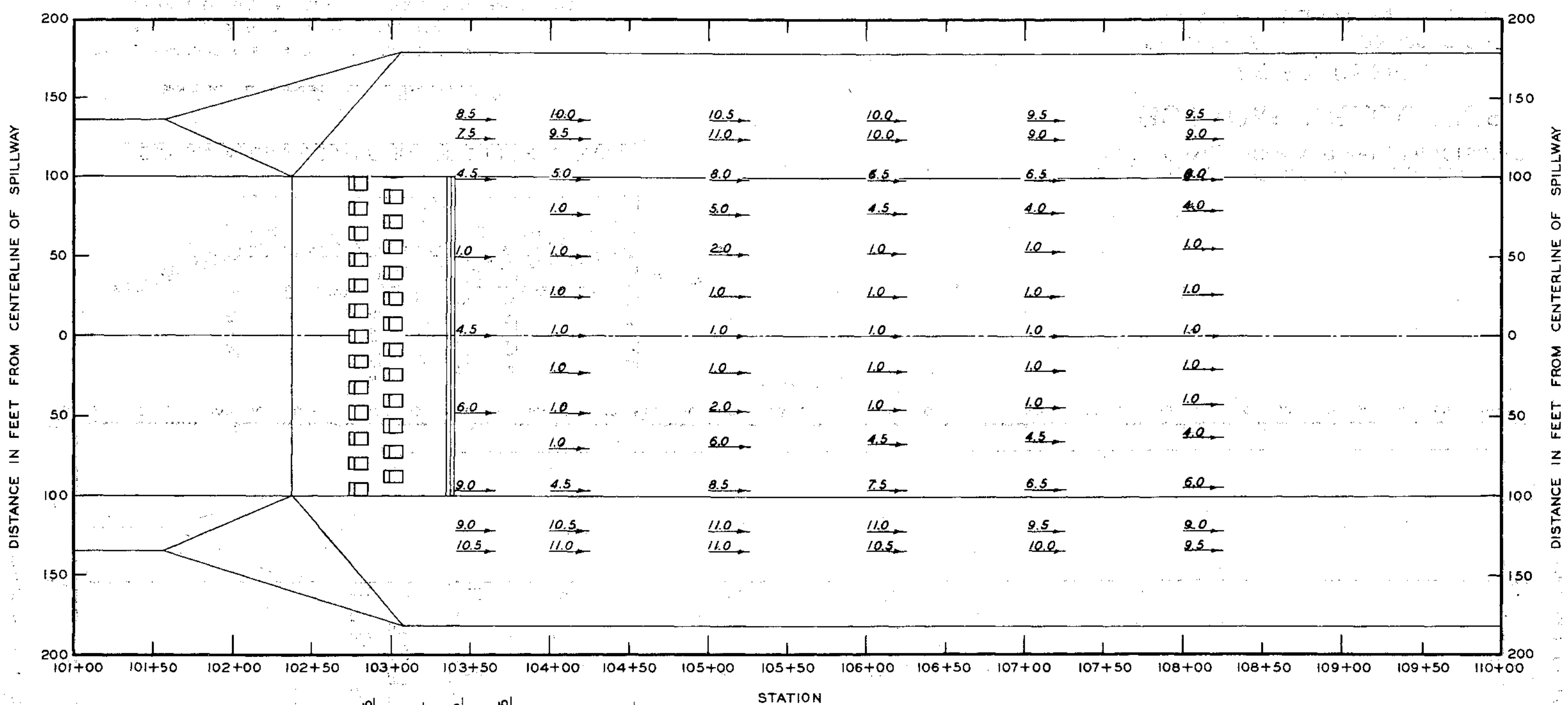
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

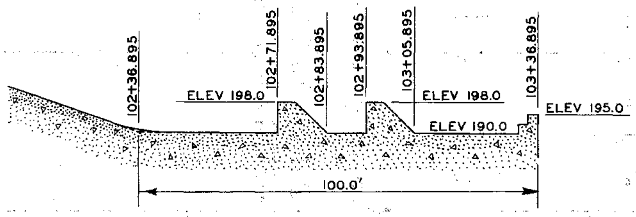
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 32 DESIGN

DISCHARGE 25,000 C F S
TAILWATER ELEVATION 216.0





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE
20 0 20 40 60 FEET

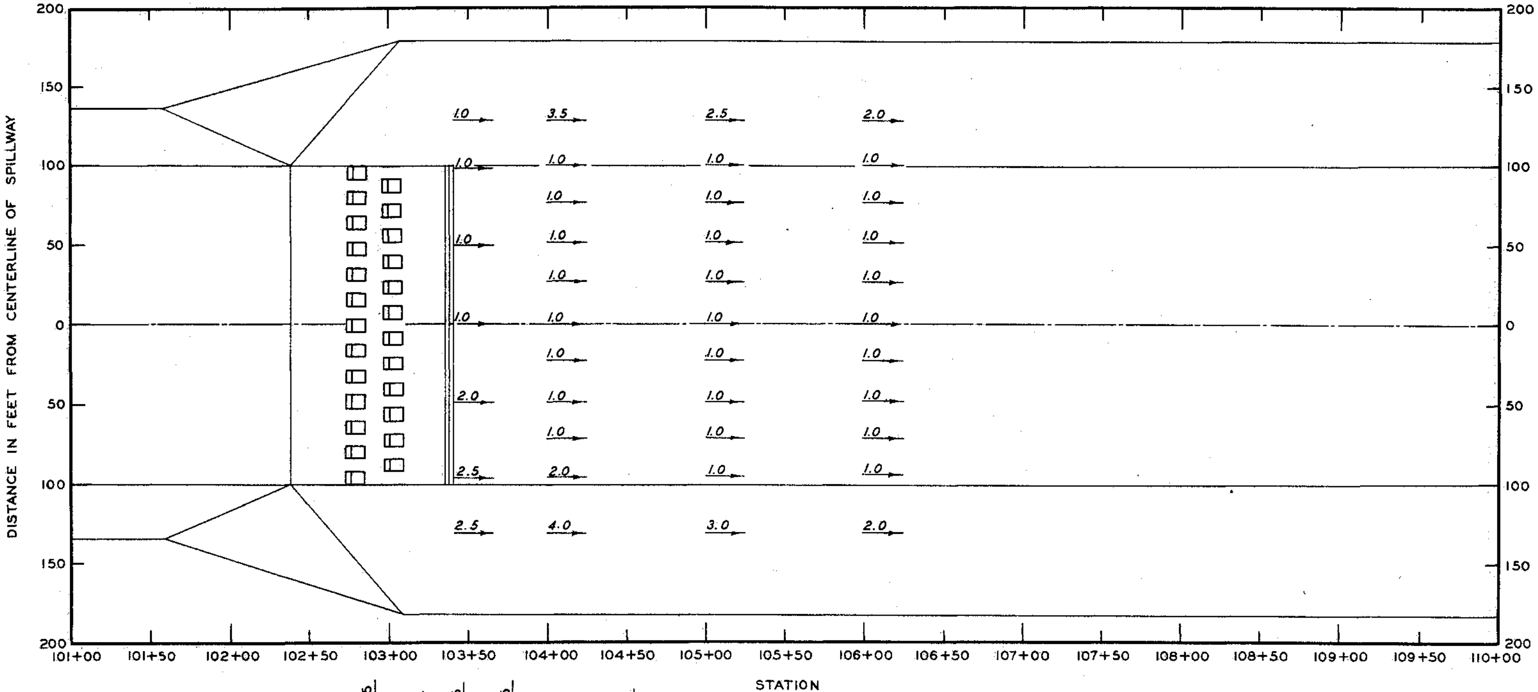
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION
VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

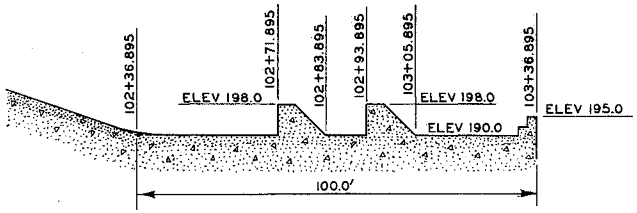
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES

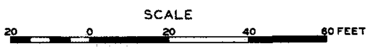
TYPE 32 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4





SECTION ALONG CENTERLINE OF STILLING BASIN



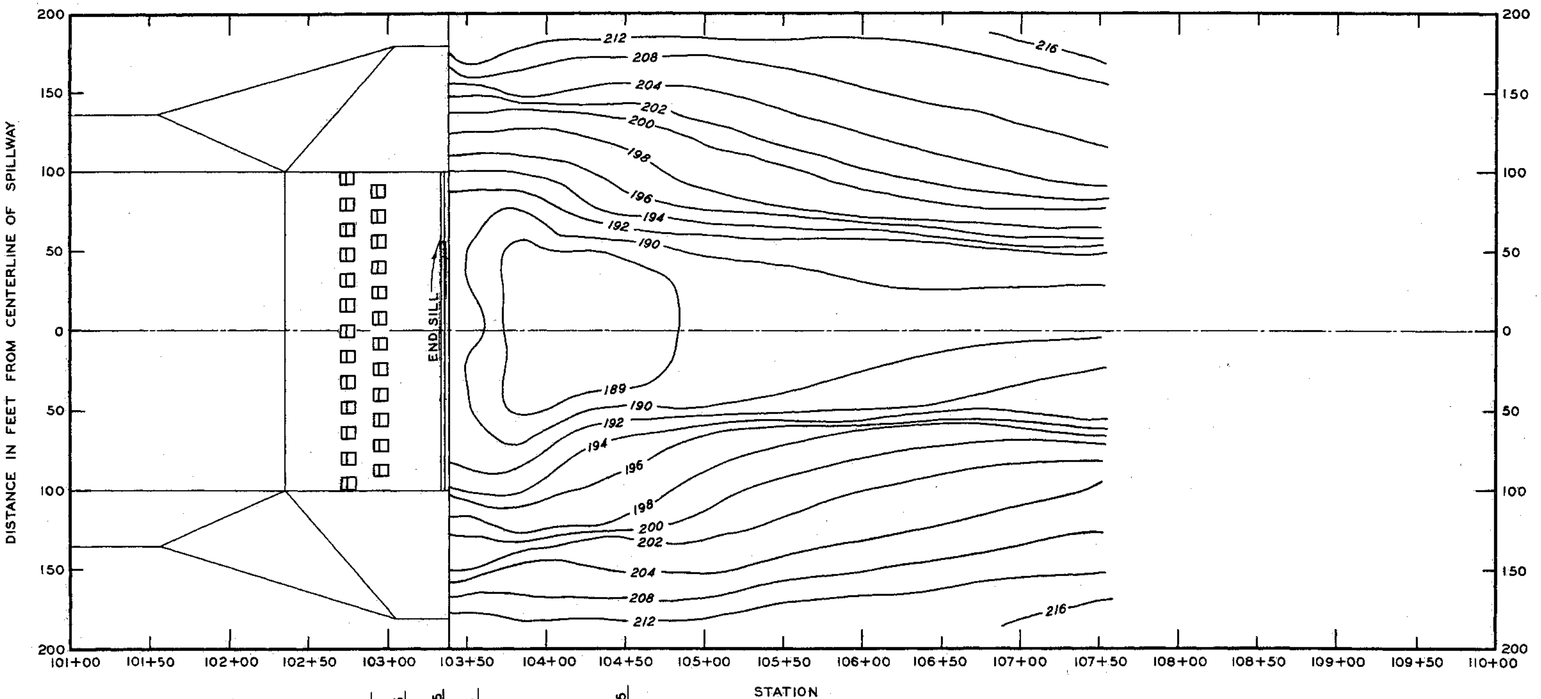
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION
VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

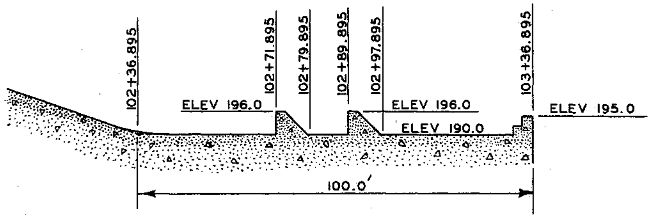
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES

TYPE 32 DESIGN

DISCHARGE 25,000 C F S
TAILWATER ELEVATION 216.0





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

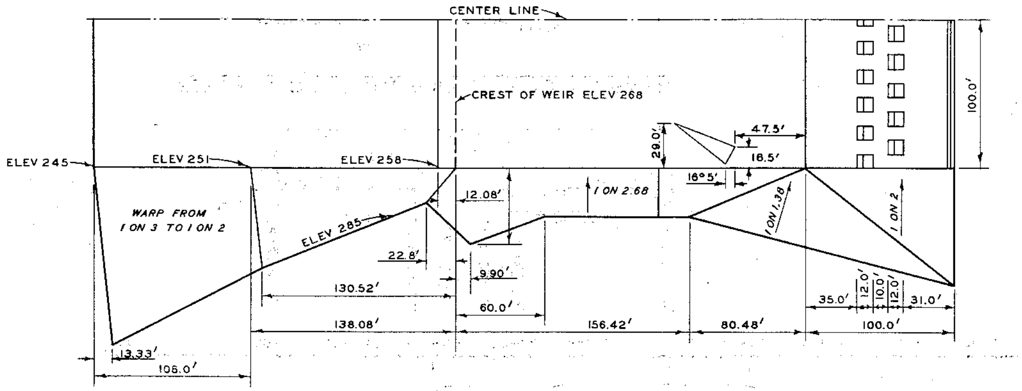
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

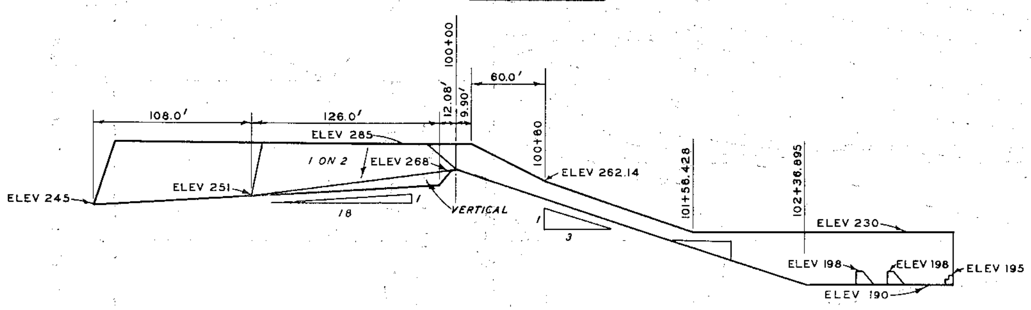
SCOUR PATTERN

TYPE 33 DESIGN

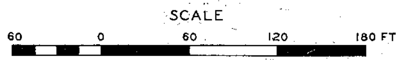
DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4

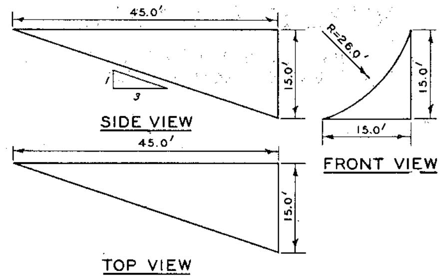


HALF PLAN



PROFILE

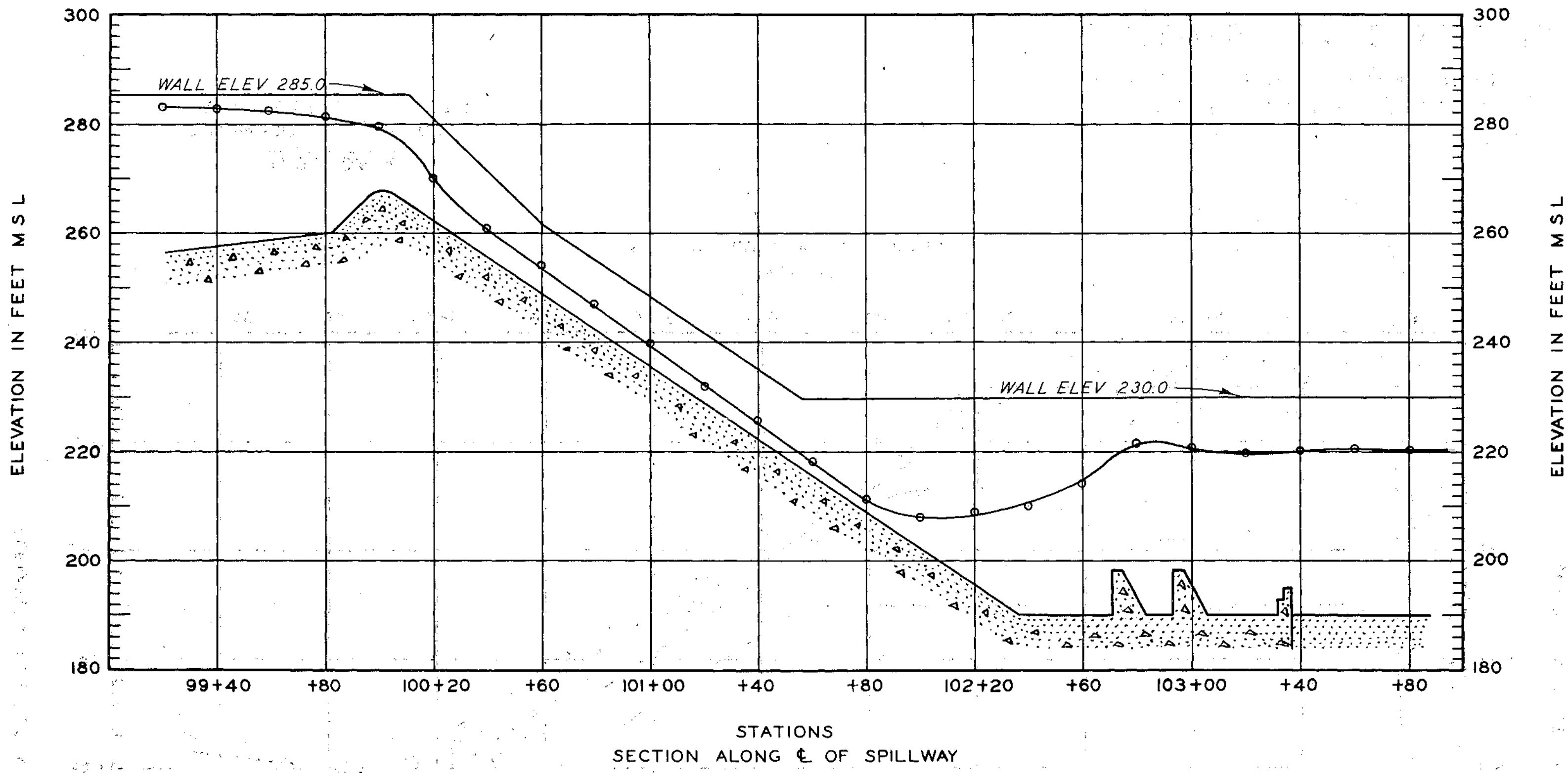




DETAIL OF DEFLECTOR

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SPILLWAY PLAN AND PROFILE
TYPE 34 DESIGN

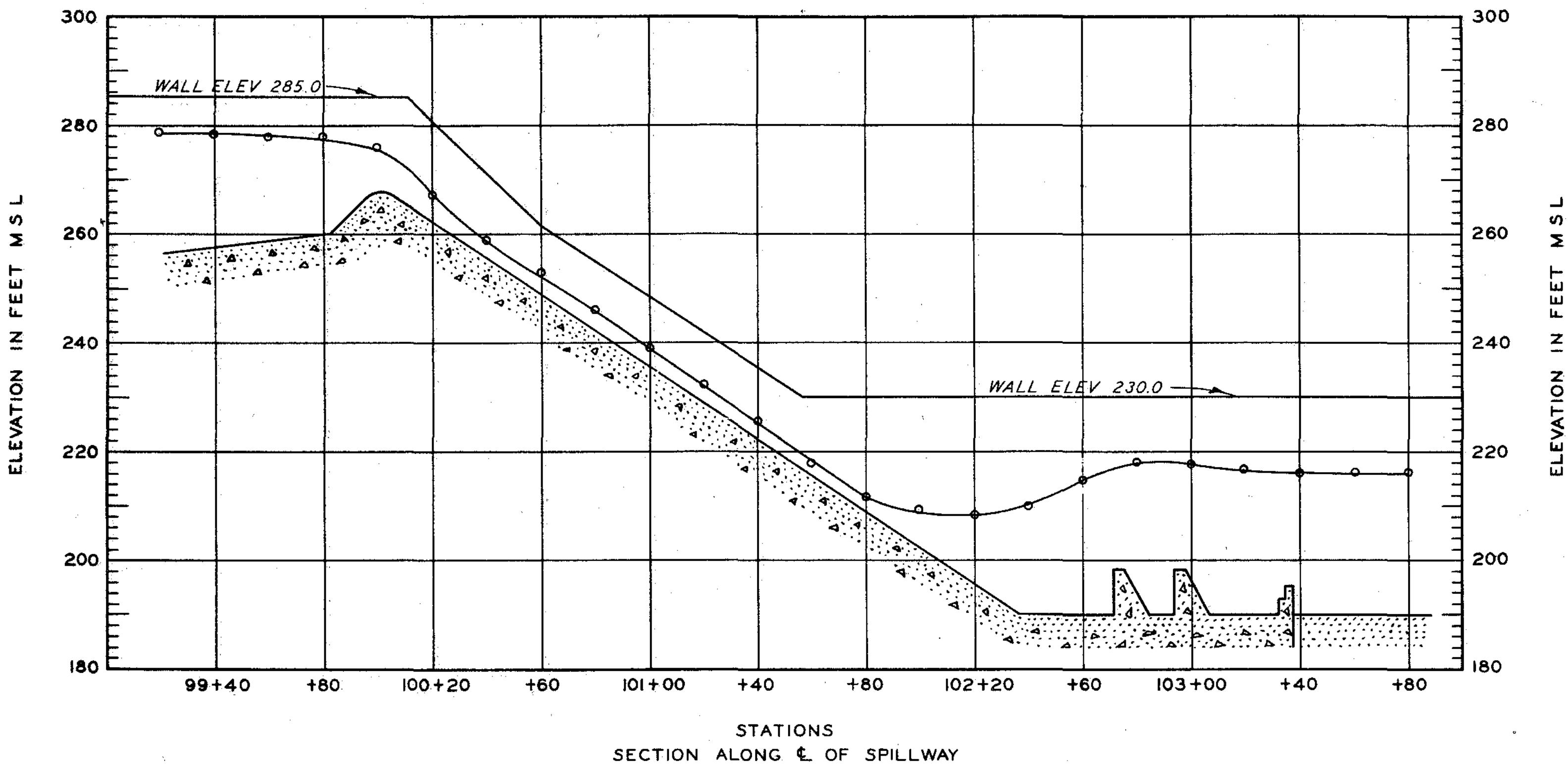


TEST DATA

DISCHARGE 50,000 C F S
TAILWATER ELEV 220.4

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

WATER–SURFACE PROFILE
TYPE 34 DESIGN

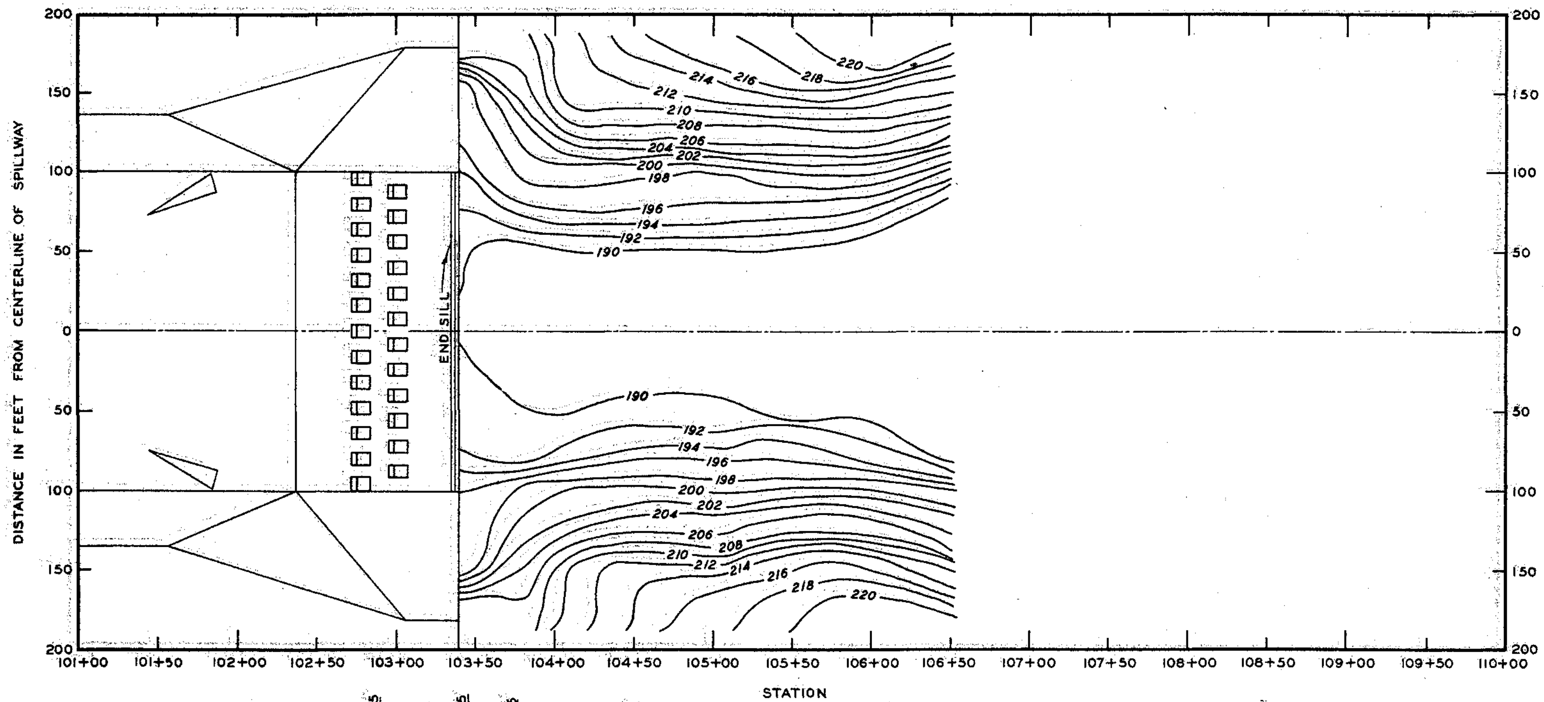


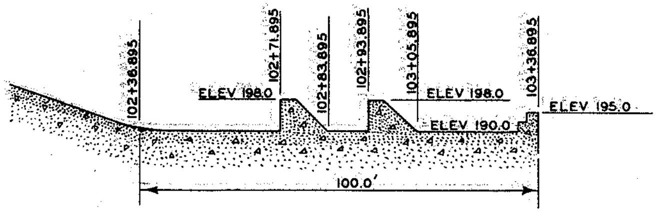
TEST DATA

DISCHARGE	25,000 C F S
TAILWATER ELEV	216.0

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

WATER-SURFACE PROFILE
TYPE 34 DESIGN





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

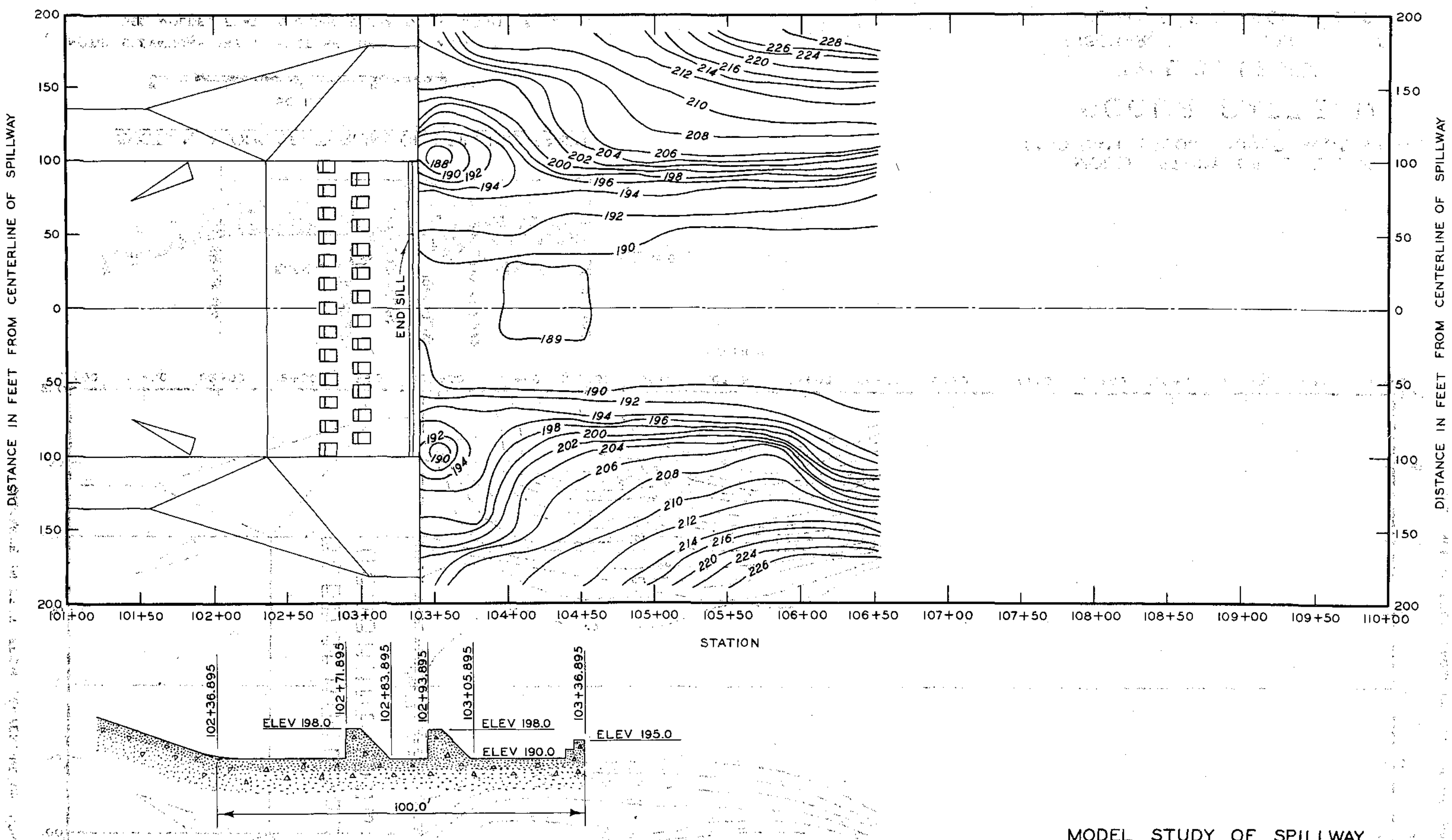
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 34 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4



SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L

BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

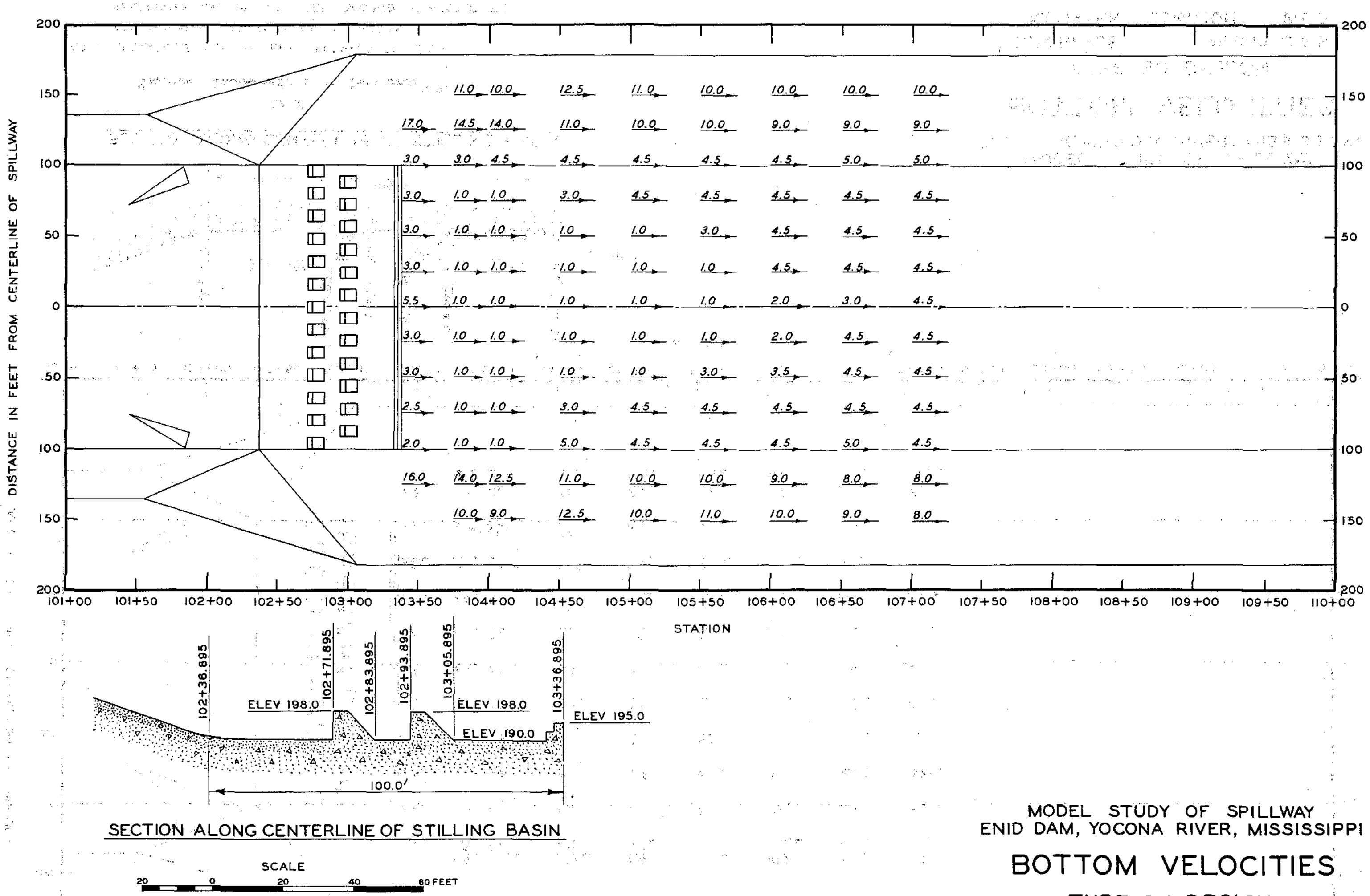
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 34 DESIGN

DISCHARGE 25,000 C F S

TAILWATER ELEVATION 216.0



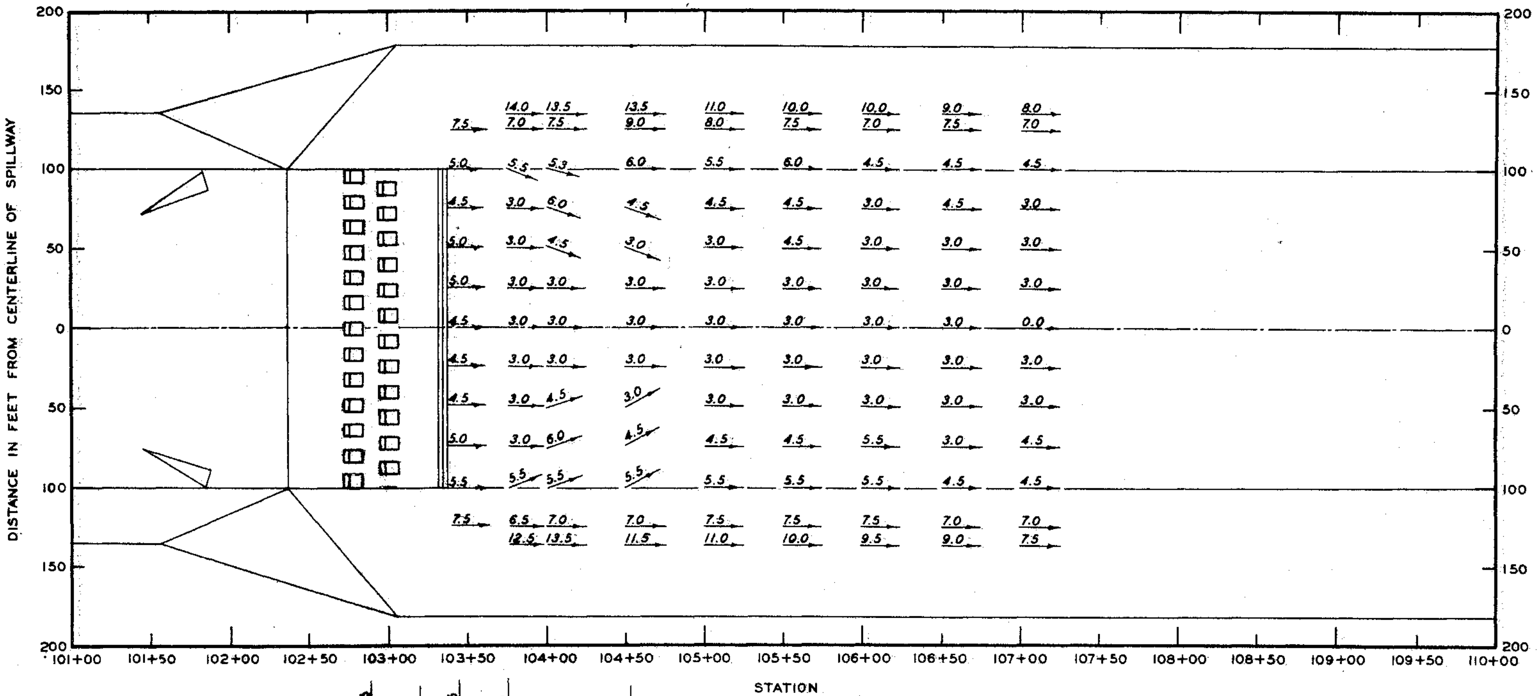
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION
VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

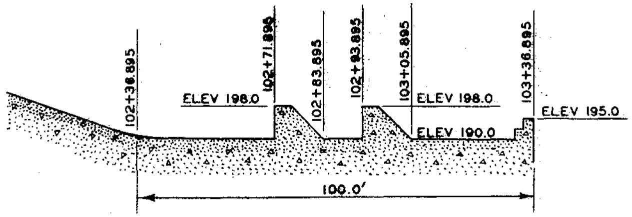
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES

TYPE 34 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

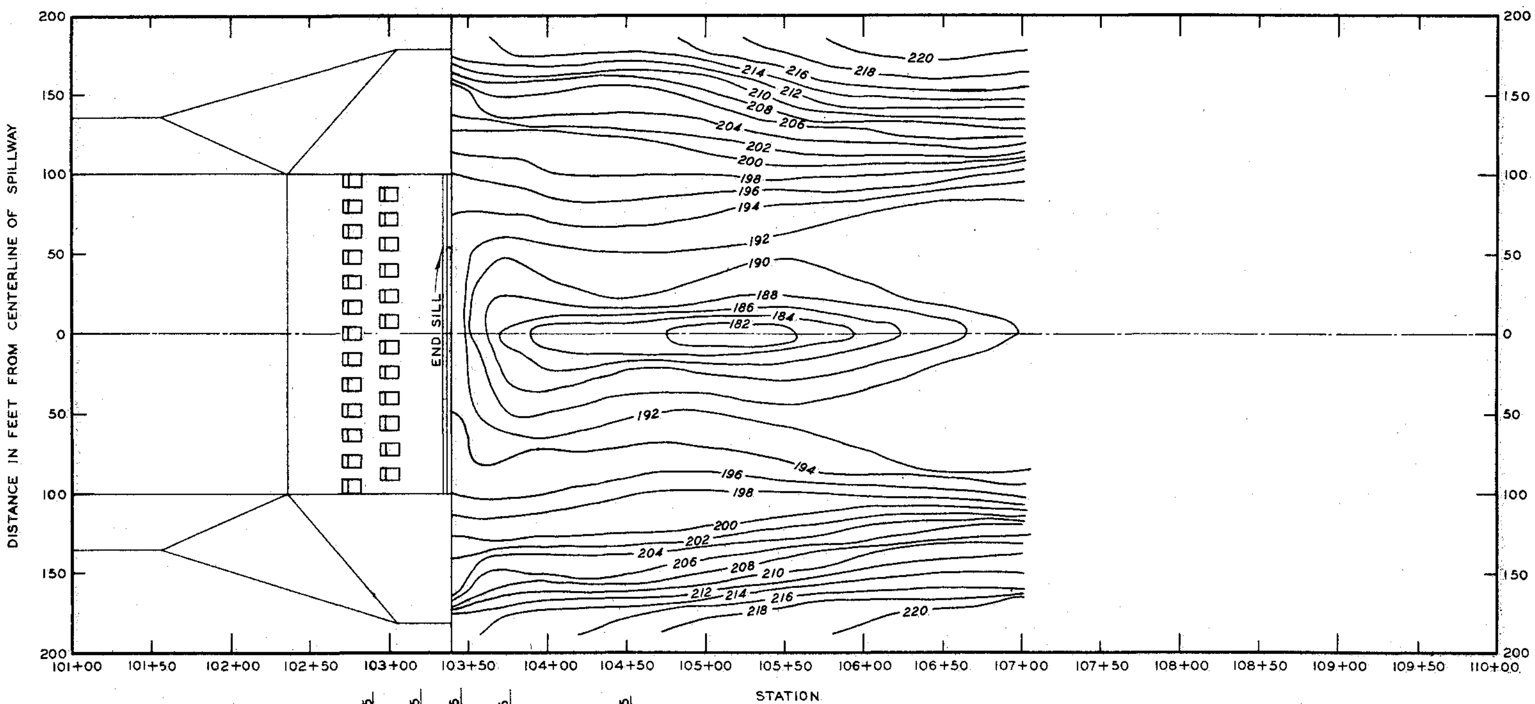
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION
VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

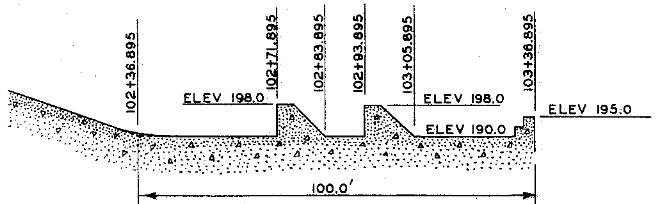
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES

TYPE 34 DESIGN

DISCHARGE 25,000 C F S
TAILWATER ELEVATION 216.0





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

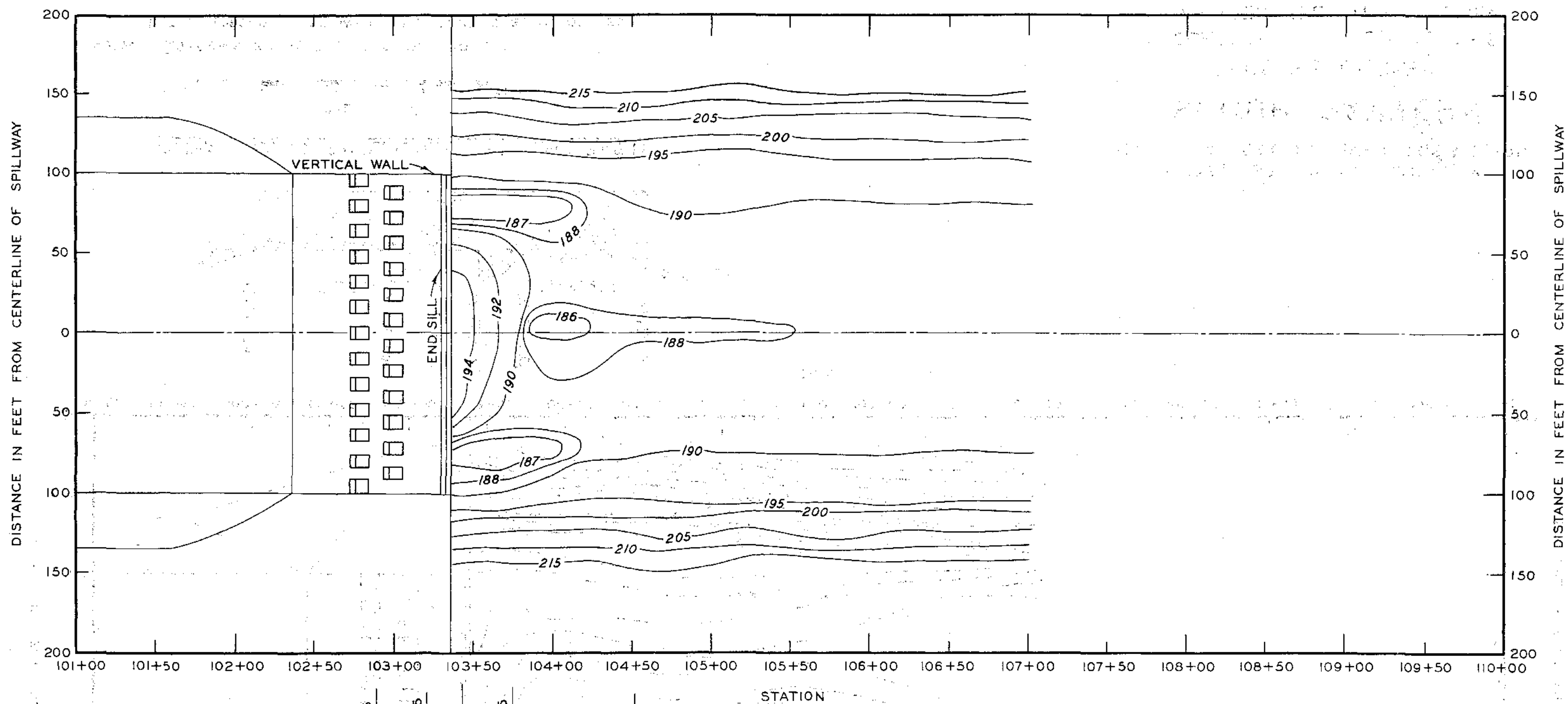
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION AT START OF TEST

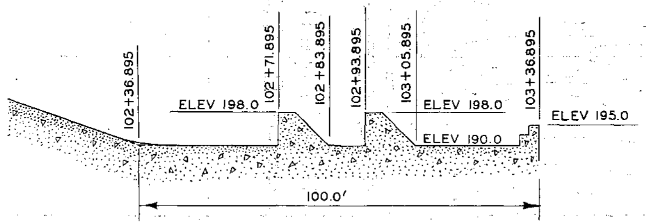
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 35 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

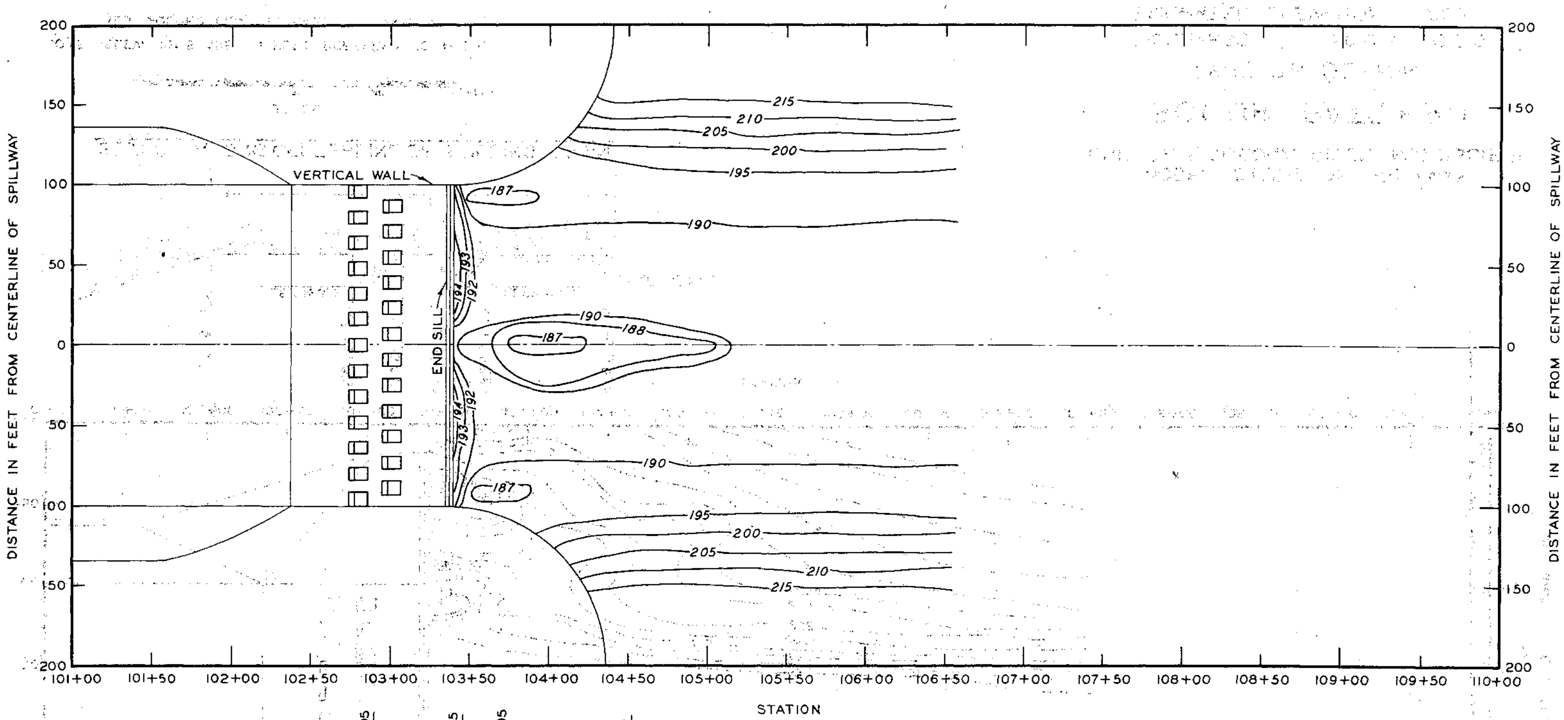
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION

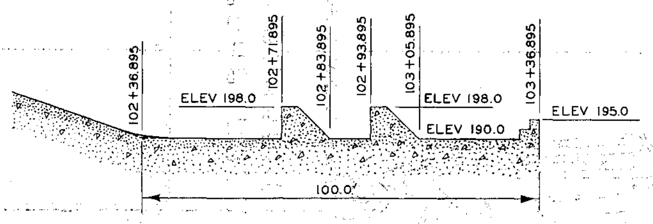
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 36 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION

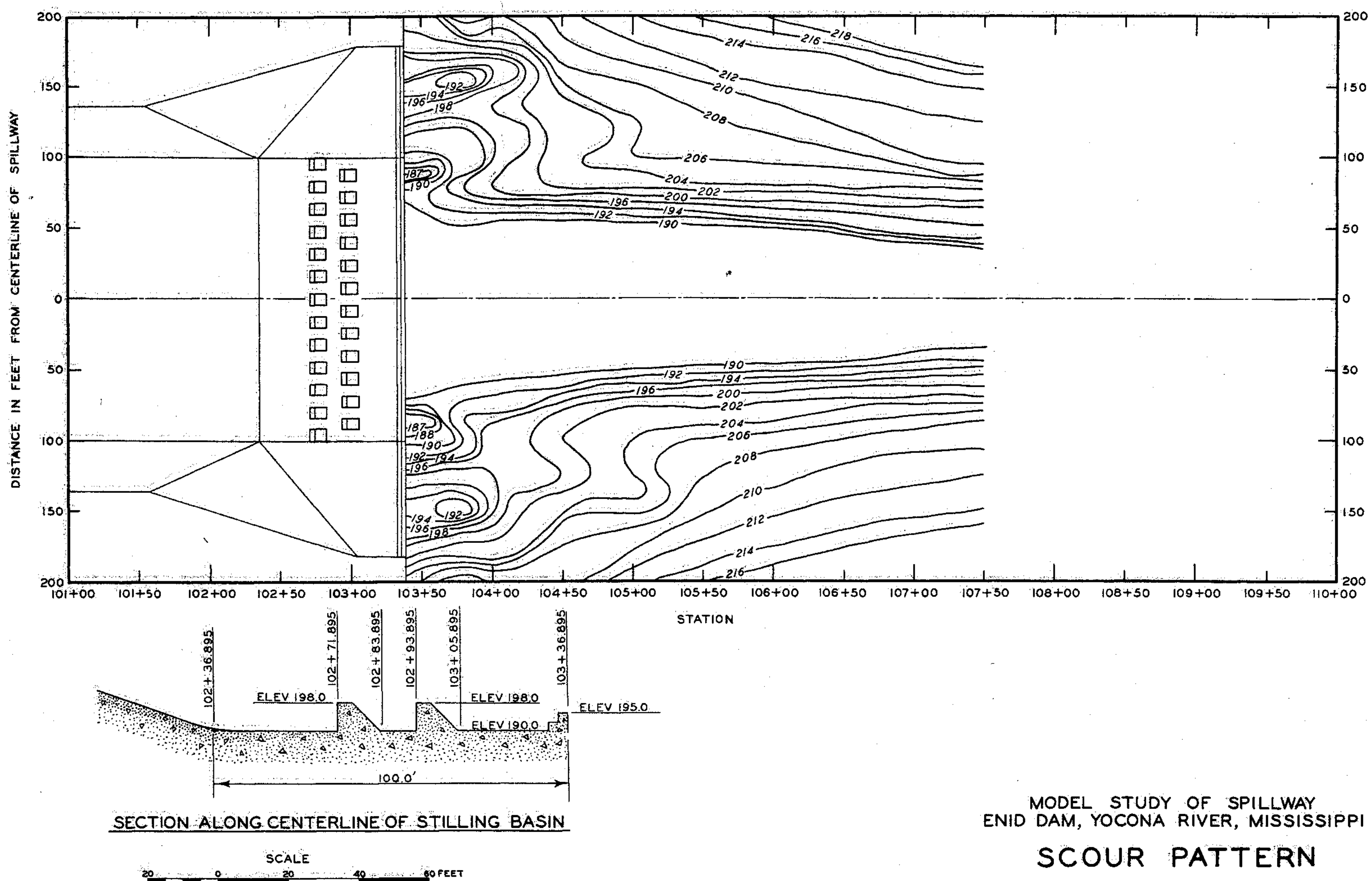
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 37 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4

PLATE 41



NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION

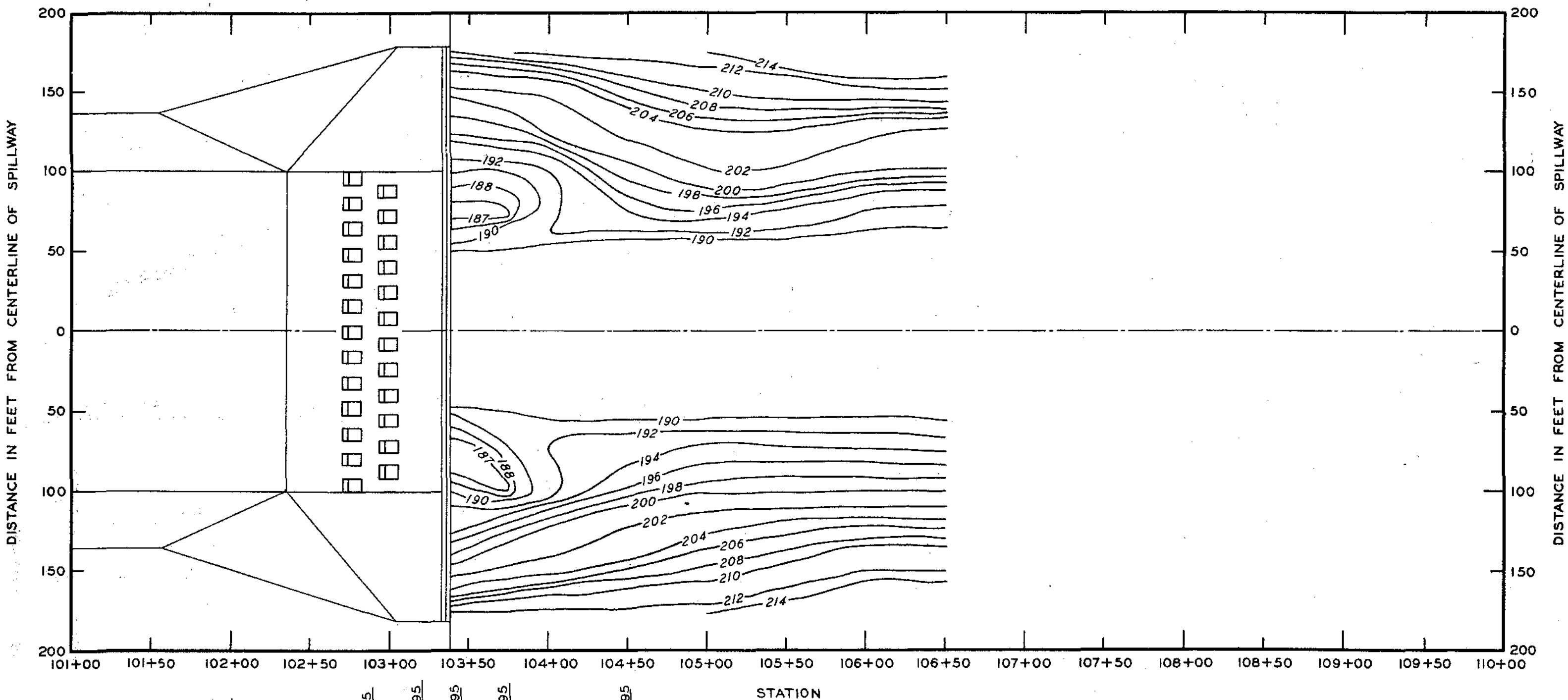
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

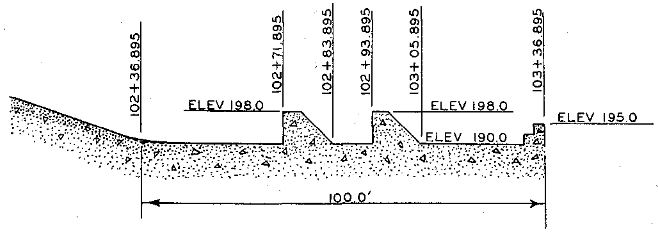
SCOUR PATTERN

TYPE 38 DESIGN

DISCHARGE 50,000 C F S

TAILWATER ELEVATION 220.4





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

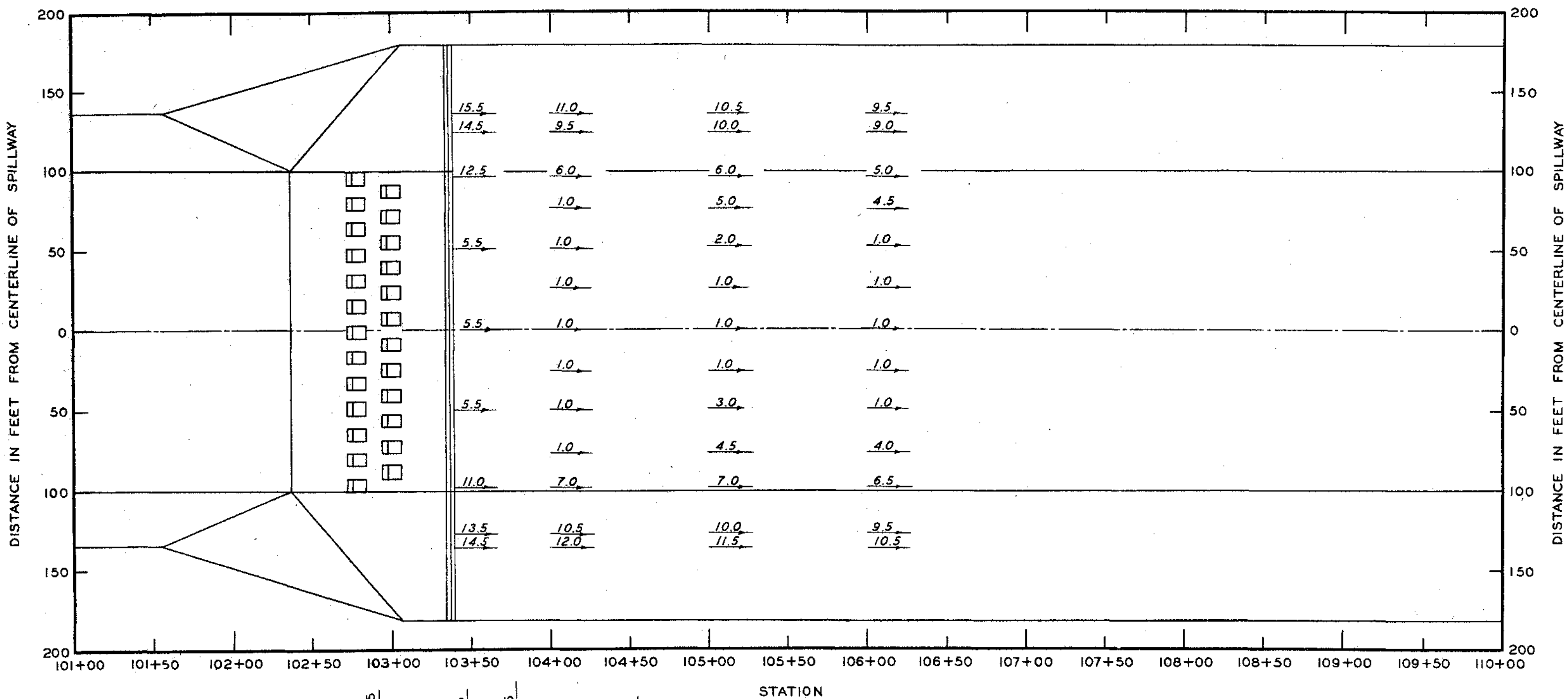
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION

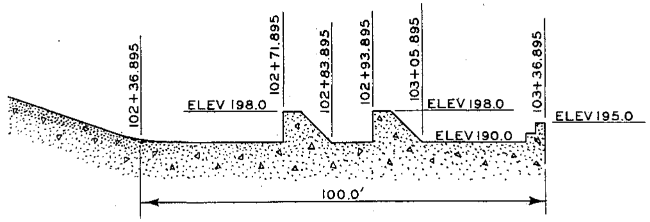
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

SCOUR PATTERN

TYPE 38 DESIGN

DISCHARGE 25,000 C F S
TAILWATER ELEVATION 216.0





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE
20 0 20 40 60 FEET

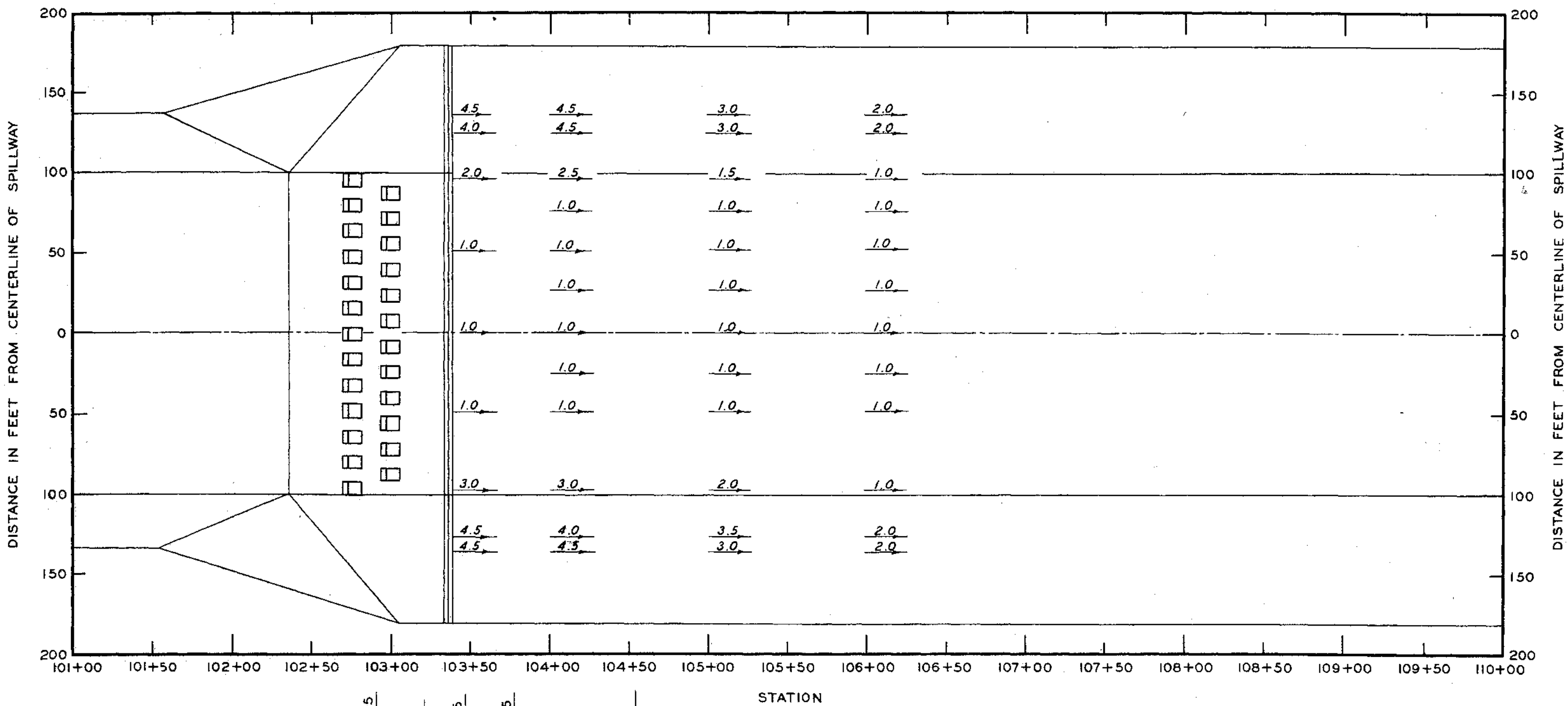
NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
BED MOLDED FLAT TO BASIN ELEVATION
VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

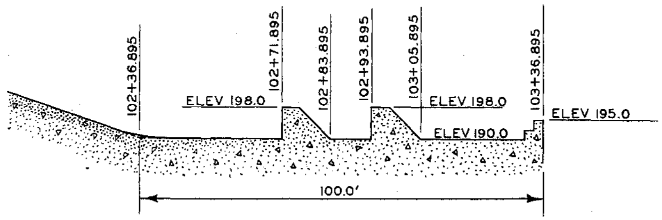
MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES

TYPE 38 DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEVATION 220.4





SECTION ALONG CENTERLINE OF STILLING BASIN

SCALE

20 0 20 40 60 FEET

NOTE: ELEVATIONS ARE IN FEET REFERRED TO M S L
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VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE

MODEL STUDY OF SPILLWAY
ENID DAM, YOCONA RIVER, MISSISSIPPI

BOTTOM VELOCITIES

TYPE 38 DESIGN

DISCHARGE 25,000 C F S
TAILWATER ELEVATION 216.0